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2026

THE PROCEEDINGS BOOK

ISPEC

INTERNATIONAL CONGRESS ON SCIENTIFIC COOPERATION & INTERDISCIPLINARY RESEARCH-II

September 02–07, 2026
Budapest, Hungary

EDITOR

Assoc. Prof. Dr. Muhammed Ali GÜNDEŞLİ



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ORGANIZING INSTITUTIONS

ISPEC

CONGRESS ID

CONGRESS TITLE

INTERNATIONAL CONGRESS ON SCIENTIFIC COOPERATION & INTERDISCIPLINARY RESEARCH-II

DATE AND PLACE

September 02–07, 2026 | Budapest, Hungary

CONGRESS STATISTICS

221 Total Accepted Papers	18 Total Rejected Papers	93 Total Papers from Türkiye	128 Total International Participants

PARTICIPANT COUNTRIES (23)

Türkiye, Nijerya, Fas, Hindistan, Bangladeş, Azerbaycan, Romanya, Cezayir, Pakistan, Endonezya, Yemen, Malezya, Etiyopya, Arnavutluk, Suudi Arabistan, Mozambik, İsrail, Kosova, ABD, Ürdün, Moldova, Güney Kore, İran, Avustralya

EVALUATION PROCESS

All applications have undergone a double-blind peer review process

PRESENTATION

Oral Presentations

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INTERNATIONAL CONGRESS ON SCIENTIFIC COOPERATION & INTERDISCIPLINARY RESEARCH-II

SEPTEMBER 02-07, 2026 | BUDAPEST, HUNGARY



CONGRESS PROGRAM

IN-PERSON SESSION - 1

03.09.2026	HALL-1

HUNGARY LOCAL TIME: 09:00-11:00

HEAD OF SESSION: Prof. Dr. Uğur BAŞARAN

Authors	Affiliation	Presentation Title
Benian Pınar AKTEPE Mervenur ŞAKACI	*Osmaniye Korkut Ata University*	Determination of the Siderophore Production Potential of Antagonistic Bacteria Isolated from Vineyard Soils
Müjgan GÜNEY Servet ARAS	*Yozgat Bozok Univeristy*	Genome Editing for Improving Fruit Quality and Postharvest Life
Müjgan GÜNEY Hakan KELES	*Yozgat Bozok Univeristy*	Hs-Spme in Fruit Aroma Analysis: Effects and Limitations of Method Selection on Volatile Profiles
Murat GÜNEY Gökçe AYDÖNER ÇOBAN	*Yozgat Bozok Univeristy*	Pangenomics and Graph Genomes: Emerging Tools for Horticultural Crop Improvement
Murat GÜNEY Selcan ÖZYALIN	*Yozgat Bozok Univeristy*	Artificial Intelligence and Machine Learning Applications in Fruit Breeding and Quality Prediction: Current Advances and Future Perspectives
Gökçe AYDÖNER ÇOBAN Servet ARAS	*Kütahya Dumlupınar Univeristy*	Biostimulants in Salt Stress Management: Physiological and Biochemical Approaches
Gökçe AYDÖNER ÇOBAN Murat GÜNEY	*Kütahya Dumlupınar Univeristy*	Approaches to Improving Yield and Product Quality with Smart Greenhouse Technologies
Gülce İLHAN İshak BAYYİĞİT Sezai ERCİŞLİ	Mardin Artuklu University	Prunus species: World distribution, importence and phytochemical composition
İshak BAYYİĞİT Sezai ERCİŞLİ	*Mardin Artuklu University*	Hawthorn: Importance and Richness in Türkiye
Berna KELES Emine Sema ÇETİN	*Yozgat Bozok University*	Green Synthesis: Use of Nanoparticles in Secondary Metabolite Production

Moderator is responsible for ensuring the smooth running of the presentation, managing the group discussion and dynamics.

IN-PERSON SESSION - 1

03.09.2026	HALL-2

HUNGARY LOCAL TIME: 09:00-11:00

HEAD OF SESSION: Prof. Dr. Belgin COŞGE ŞENKAL

Authors	Affiliation	Presentation Title
Aysen KOÇ	*Yozgat Bozok University*	Nutritional Value and Evaluation Methods of Chokeberry (*Aronia melanocarpa*)
Belgin COŞGE ŞENKAL	*Yozgat Bozok University*	The Importance of the Major Chemical Components in the Essential Oils of Three Salvia Species Endemic to Türkiye
Sultan ACUN Hülya GÜL	*Amasya University*	Effects of Precooked Lentil and Common Bean Flour Blends on the Nutritional, Physical, and Textural Properties of Muffins
Mevlüt GÜL Hülya GÜL	Süleyman Demirel University	A Comparative Analysis of Pasta Production, Consumption, And Trade Patterns With Focus on Türkiye
Volkan OKATAN Şahin IŞIK Melike URFALI Şafak ATAY İbrahim BULDUK Mustafa Emre ŞİMŞEK Ayşegül Türk BAYDIR	*Eskisehir Osmangazi University*	Phenolic and Organic Acid Profiles of Black Mulberry (*Morus nigra* L.) Genotypes Identified in the Rural Areas of Eskisehir Province
Melike Urfalı Volkan OKATAN	*Eskisehir Osmangazi University*	The Effect of Biostimulant Applications on Pomological Values in Black Currant (*Ribes nigrum* L.)
Selçuk GÜRÇAM Güven KORKUT	*Iğdır University*	Competitive Securitization: How Are Global Conflicts Undermining The Political Priority Of The Climate Crisis?
Ayşe ÖLMEZ	*Tokat Gaziosmanpaşa University*	Microplastic Pollution in Aquaculture: Sources, Biological impacts, and Management Strategies
Eda CEYLAN Mustafa Enes BÜYÜK Derya AYRAL ÇINAR	*Gebze Technical University*	Optimization of Urea and NBPT Inhibitor-Containing Urea Use for Reducing N_2O Emissions from Agricultural Soils

Moderator is responsible for ensuring the smooth running of the presentation, managing the group discussion and dynamics.

IN-PERSON SESSION - 1

03.09.2026	HALL-3

HUNGARY LOCAL TIME: 09:00-11:00

HEAD OF SESSION: Dr. Funda ÇİMEN AÇIKGÜL

Authors	Affiliation	Presentation Title
Mustafa BULAT Mayram KARADAĞ	*Atatürk University*	The Transformation of Material in Anselm Kiefer's Art: Waste Memory, and The Production of Aesthetic Meaning
Sultan AKDAG TURKAY Alireza KHATAEE	*Gebze Technical University*	Rapid Photocatalytic Degradation of Azo Dyes Using Tivalc Max Phase
Cengizhan KARACA	*Gaziantep University*	Today Cash, Performance Later: Evidence of Panel Causality Due To Lag in An Emerging Economy
Sercan AYDIN	*Gaziantep University*	Time-Frequency Dynamics of Energy Intensity in Türkiye: Growth, Urbanization, and Financial Development-Wavelet Coherence Approach
Burcu PALA Ceren KÖKÇÜ Coşkun AYDINER	*Gebze Teknik University*	Simulation Study on Nanofiltration Pretreatment in Seawater Reverse Osmosis Desalination Using Wave ® Software
Mehmet Akif DESTEK Gamze DESTEK	*Gaziantep University*	Understanding Green Finance and the Energy Transition: A Multidimensional Approach
Funda ÇİMEN AÇIKGÜL Merve Nur GÜNEY	*Ağrı İbrahim Çeçen University*	Bibliometric And Knowledge Mapping Analysis of Spatial Transcriptomics Research on Host–Microbiome Interactions (2018–2026)
Funda ÇİMEN AÇIKGÜL Mücella BAYIRLI NACAROĞLU	*Ağrı İbrahim Çeçen University*	In Vitro Assessment of the Antimicrobial Activity of Natural Bioactive Compounds Against Pseudomonas aeruginosa and Staphylococcus aureus

Moderator is responsible for ensuring the smooth running of the presentation, managing the group discussion and dynamics.

IN-PERSON SESSION - 2

03.09.2026	HALL-1

HUNGARY LOCAL TIME: 11:30-13:00

HEAD OF SESSION: Prof. Dr. Hülya GÜL

Authors	Affiliation	Presentation Title
Meryem AYBAS	*Zonguldak Bülent Ecevit University*	An Investigation on the Role of Human Resource Management for Decent Work with Dignity
Mehmet Ali GÜL Elif Ece GÜL	*Burdur Mehmet Akif Ersoy University*	Artificial Intelligence in Oral and Maxillofacial Radiology: Current Applications, Clinical Impact, and Future Perspectives
Meral TOPRAK Semanur SEKİ	*Marmara University*	An Analysis of Digital Interest in Magnesium, Vitamin D, Omega-3 and Zinc Dietary Supplements in Turkey Through Google Trends Data
Eda AYDIN Arzu BAYRAMOĞLU	*Zonguldak Bülent Ecevit University*	Does Business Website Ownership Matter for Foreign Trade? Evidence From OECD Countries
Elif Ece GÜL Mehmet Ali GÜL	*Akdeniz University*	Dental and Oral Manifestations of Celiac Disease: Clinical Patterns and Diagnostic Significance
Malike BİLEYDİ KOÇ	*Marmara University*	An Example of the Analysis of Atatürk's World of Thought: "Memories of Karlsbad"
Nursel KÖKSAL	*Akdeniz University*	Reflections of Atatürk's Solidarist Thought on The Nation Schools (Millet Mektepleri)
Ersin BERK	*Sakarya University of Applied Sciences*	The Representation of Reading in André Kertész's Esztergom (1915) And Budapest (1971)

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IN-PERSON SESSION - 2

03.09.2026	HALL-2

HUNGARY LOCAL TIME: 11:30-13:00

HEAD OF SESSION: Dr. Emine ATAMAN

Authors	Affiliation	Presentation Title
Bilge Nur GÜNEŞ	*Marmara University*	A General Overview for Türkiye-Hungary Industrial Relations for Strategic Cooperation
Bilge Nur GÜNEŞ	*Marmara University*	Evaluation of the International Mobility Attractiveness Of Leading Universities in Seven Central European Countries (CEC) Considering Engineering and Technology Using the Mabac Method
Yıldırım GÜNDOĞDU Habibe GÜNDOĞDU	*Ministry of Education*	Cellular Health in Sports: Exercise-Induced Mitochondrial Adaptations and Histological Changes in Diabetic Pathologies
Emine ATAMAN	*Artvin Çocuh University*	Rethinking Traumatic Loss and Grief: New Perspectives on Social Work with the Salutogenic Model
Orhan GÜNDÜZ Ahmet ASLAN Osman UYSAL Mehmet AYDOĞAN Serhan CANDEMİR Cuma AKBAY	*Malatya Turgut Özal University*	Real Change in Agricultural Land Prices in Turkey After the 2023 Earthquakes: A Comparative Analysis of Four Provinces
Orhan GÜNDÜZ Ahmet ASLAN Osman UYSAL Mehmet AYDOĞAN Serhan CANDEMİR Cuma AKBAY	*Malatya Turgut Özal University*	Earthquake-Induced Disruptions and The Reconfiguration of Agricultural Land Markets: Evidence From Producer Behavior in Türkiye
Yasin ÇAKIR Yeşim AYDOĞAN	*İnönü University*	The Industrialization of Nature: the Aesthetic Transformation of Landscape Painting

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IN-PERSON SESSION - 2

03.09.2026	HALL-3

HUNGARY LOCAL TIME: 09:00-11:00

HEAD OF SESSION: Dr. Seçil Nazife PARLAK

Authors	Affiliation	Presentation Title
Nurcan KILIÇ Adnan GÜLAÇTI Pelin CEYLAN Oktay KILIÇ	*Gazi University*	Language Skills and Anxiety Levels in Children with and Without Language Disorder: A Comparative and Correlational Study
Yunus DURBİN Murat KOÇ Özlem SARIÖZ İnci ÜNLÜ	*Niğde Ömer Halisdemir University*	Removal Of Ponceau 4r Dye from Aqueous Solutions Using A Green- Synthesized Bean Pod–Cobalt Ferrite Magnetic Composite
Seçil Nazife Parlak Ayla Arslan Habibe Gündoğdu	*Ağrı İbrahim Çeçen University*	The Second-To-Fourth Digit Ratio (2d:4d) As A Prenatal Developmental Biomarker: A Bibliometric and Knowledge-Mapping Analysis of the Global Literature
Seçil Nazife PARLAK Merve Nur GÜNEY Muhammet Volkan BÜLBÜL	*Ağrı İbrahim Çeçen University*	Compartment-Specific Distribution of TAS1R1 and TAS1R2 Taste Receptor Subunits in the Female Rat Rectum
Fatma Sevde DENLİ Ayşegül KARATAŞ Ahmet KARATAŞ	Niğde Ömer Halis Demir University	Drugs Developed From Animal Venoms : From Natural Toxins To Modern Pharmacotherapy
Meral MİRALOĞLU Salih ÇETINER Filiz KIBAR	*Çukurova University*	Cytokine Profiling in Young Adults: Determining Reference Ranges for Inflammatory and Anti-İnflammatory Balance

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- Speakers must be connected to the session **10 minutes before** the presentation time.
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TECHNICAL INFORMATION

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02.09.2026 / ONLINE / SESSION-1 / HALL-1

Budapest Local Time: 09:00-11:00 Ankara Local Time: 10:00-12:00

Zoom Meeting ID: 860 5266 6988 / Zoom Passcode: 020202

HEAD OF SESSION: Dr. Coşkun AKÇA

Authors	Affiliation	Presentation Title
Aytan JAFAROVA	*Bakü Devlet University*	A Comparative Geographical Analysis of Digital Cartographic Representation in the Historic Tourism Cities of Sheki and Amasya
Seyaddin JAFAROV	*Nakhchivan State University*	Study of The Structure, Electrical and Optical Properties of Thermal Evaporation-Synthesized Cdse;0.5%Ho Nanocrystal
Gülsemin AKÇA Coşkun AKÇA	*Tokat Gaziosmanpaşa University*	”We're Trying to Please the Algorithms”: The Consequences of Algorithmic Management in Media Labour
Aybüke GÜÇLÜ DEMİR Görkem GÖKÇE YİĞİT	*Ministry of National Education*	A Reading Model of İlhan Berk’s poem Taymis from the Perspective of Environmental Humanities
Görkem GÖKÇE YİĞİT Aybüke GÜÇLÜ DEMİR	*Sigma Educational Institutions*	The Other Self Revealed Under the Full Moon: Dual Characterization and Delayed Meaning in Mark Turner’s Short Story
Metin CEYLAN	*Uşak University*	FROM HEEDLESSNESS TO GNOSİS: THE SLEEP METAPHOR İN THE DĪVĀN OF SHAYKH GĀLİB
Yasemin ÇELİK	*Hatay Mustafa Kemal University*	On the Use of Verbals in Works From the Republican Period
Hasan ERYÜRÜK Fatma TOPUZ ERYÜRÜK	*Afyon Kocatepe University*	DIGITAL STATE CAPACITY AND THE INSTITUTIONALIZATION OF ARTIFICIAL INTELLIGENCE GOVERNANCE A COMPARATIVE ANALYSIS OF DIGITAL PUBLIC ADMINISTRATION CAPACITY
Hasan ERYÜRÜK Fatma TOPUZ ERYÜRÜK	*Afyon Kocatepe University*	THE EFFECT OF DIGITAL PROGRESS ON INEQUALITY REDUCTION AND THE TRANSFORMATION OF DIGITAL STATE CAPACITY IN THE AGE OF ARTIFICIAL INTELLIGENCE

(All speakers required to be connected to the session 10 min before the session starts)
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02.09.2026 / ONLINE / SESSION-1 / HALL-2

Budapest Local Time: 09:00-11:00 Ankara Local Time: 10:00-12:00

Zoom Meeting ID: 860 5266 6988 / Zoom Passcode: 020202

HEAD OF SESSION: Prof. Dr. Sevgi GEZİCİ

Authors	Affiliation	Presentation Title
Hacer POLAT Çetin YAĞCILAR Muazzez GÜRGAN ESER	*Tekirdağ Namık Kemal University*	Effect of Salt Concentration (10 g/L) on Protozoan Contamination and Growth in Chlorella sorokiniana Cultures
Melahat İrem ÖDEMİŞ Çetin YAĞCILAR Muazzez GÜRGAN ESE	*Tekirdağ Namık Kemal University*	Comparison of the Morphological Effects of Different Incubation Environments on Zebrafish (Danio rerio) Embryos
Bahadır AYDAŞ	*Duzce University*	Development of Ultrasonic Cavitation-Assisted Bi_2O_3/CeO_2 Hybrid-Coated Hemp Fabrics and Investigation of Their Multifunctional Radiation Shielding Performance
Kaan KARAASLAN	*Antalya Bilim University*	The Legal Characterization Of Parametric Insurance As An Insurance Contract: A Purposive And Functional Interpretation Of Article 1401 Of The Turkish Commercial Code
Begüm İLBAY VATAN	*Kahramanmaras Sutçu Imam University*	Storytelling in the Transformation of Kahramanmaraş's Gastronomic Heritage into Experiential Value: A Model Proposal
Sevgi GEZİCİ Muhammet Ali GÜNDEŞLI	*Gaziantep University*	Potential Anticancer Effects of Pomegranate Fruit Extract on Non-Small Cell Lung Cancer Cells: A Comparison with Non-Malignant Lung Fibroblasts
Gözde NOGAY KURTULUS	*Mersin University*	Effects of Seaweed Extract Use on Yield, Quality, and Stress Tolerance in Fruit Growing
Gözde NOGAY KURTULUS Muhammet Ali GÜNDESLİ	*Mersin University*	Current approaches to enhancing early harvest opportunities in apricots

(All speakers required to be connected to the session 10 min before the session starts)
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02.09.2026 / ONLINE / SESSION-1 / HALL-3

Budapest Local Time: 09:00-11:00 Ankara Local Time: 10:00-12:00

Zoom Meeting ID: 860 5266 6988 / Zoom Passcode: 020202

HEAD OF SESSION: Muhammad Faisal

Authors	Affiliation	Presentation Title
Joy Happiness YISA Charles Yakubu MAKUN Ahmadu S. ALFA	*Federal University of Technology*	Acoustic Integrity vs. Tropical Ventilation: assessing Building Envelope Performance for noise mitigation in day Secondary Schools of Minna, Nigeria
Ananda MAJUMDAR	*Harvard University*	Navigating The Digital Landscape: The Interplay Of Religion And Technology In Contemporary Society
Ouassila RIOUCHI Khalid ELKALAY Mourad BAGHOUR	*Cadi Ayyad University*	Protecting Fish Resources from Marine Pollution: Challenges and Sustainable Solutions
Ratna SEPTIYANTI Harsono Edwin PUSPITA Doni Sagitarian WARGANEGARA Agus Zahron IDRIS	*University of Lampung*	Spatial And Gendered Expenditure Dynamics: Welfare Divergence In West Java
Muhammad FAISAL	*Joint Director (AICU) at Ministry of IT & Telecommunication*	Agentic Artificial Intelligence for Autonomous Enterprise Workflow Automation Transforming Business Operations through Intelligent Decision-Making
Marvellous Oluwatoyin OPALEKE Lateef Ademola LAWAL	*Federal University of Technology*	A Review on Indigenous Play Traditions as Cultural Resources for Early Childhood Environments in Nigeria.
Ojoajogwu Josiah ATANU Paul Baba HARUNA	*Federal University of Technology Minna*	Daylighting Design Strategies For Tropical Architecture Studios: A Systematic Review
Shahzaib KHAN	*Government College University Faisalabad*	Reduced Graphene Oxide-Integrated Copper Aluminate Nanocomposite For High-Performance Supercapacitors
Soukaina EL BOURACHDİ Lekbira EL MERSLY Yassine RAKCHO Ali Raza AYUB Abdelhay EL AMRİ Mahdi LECHHEB Amal LAHKİMİ	*Sidi Mohamed Ben Abdellah University*	Eco-Friendly synthesis of Chitosan@TiO_2 nanocomposite for efficient dye adsorption and textile wastewater treatment: a combined experimental and theoretical study

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02.09.2026 / ONLINE / SESSION-1 / HALL-4

Budapest Local Time: 09:00-11:00 Ankara Local Time: 10:00-12:00

Zoom Meeting ID: 860 5266 6988 / Zoom Passcode: 020202

HEAD OF SESSION: Zubia SHAH

Authors	Affiliation	Presentation Title
Ion PETRE Flavia BARNA Miruna Lucia NACHESCU Razvan BOBORA Danian Ionel POPA Tiberiu BULEU Cristian PETRE	*"Victor Babes" University of Medicine and Pharmacy Timisoara*	Artificial Intelligence–Driven Prediction of Treatment-Related Hematologic Changes in Stage III Cervical Cancer
Aminu IDI Ibrahim USMAN ZUBAIR Abdullahi NASIR	*Bayero University*	Mycochemical Profiling, Antioxidants Properties and Antibacterialal Activities of Ethyl Acetate Extract of Bondarzewia berkeleyi
Zubia SHAH	*Khyber Girls Medical College*	Exploring the Link Between Serum Myostatin and Sarcopenia in Middle-Aged Adults
Bandana CHOWDHURY Jayashree CHOWDHURY Sourav DEURI Nikita DAS	*Gauhati University*	Intellectual Property Rights, Green Innovation, and Environmental "Sustainability: Evidence from Assam and Northeast India"
BEKRI MERIEM Bouchenak OUAHIBA CHAALEL ABDELMALEK Dahou SARA KELOUA DALILA	*Université Abdelhamid Ibn Badis Mostaganem.*	Assessment of Metallic Element Content and Safety of Moringa oleifera Grown in Algeria
Babita GUPTA	*Institute of Technology and Management Gida Gorakhpur*	Revolutionizing Cancer Diagnosis: The Potential of 3D Printed Nanosensors
Ibrahim Sani DIKKO	*Umaru Musa Yar'adua University Katsina,*	Biochemistry of Today, Medicine of Tomorrow: Intriguing Facts, Figures, and Molecular Evidence for Biochemistry as the Foundation of Modern Medicine
Mohsin KHAN Mohammad PARVEJ Athar Ali KHAN	*Aligarh Muslim University Aligarh*	Bayesian Competing Risks Analysis Using Flexible Half-Logistic-G Hazard Models
Md Norim BHUYAN Md Nasir UDDIN Sanjida NOUSIN Rafsun RAHMAN Sajib HASAN	*St. Francis College*	Artificial Intelligence in Clinical Practice and Its Future Perspectives

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02.09.2026 / ONLINE / SESSION-1 / HALL-5

Budapest Local Time: 09:00-11:00 Ankara Local Time: 10:00-12:00

Zoom Meeting ID: 860 5266 6988 / Zoom Passcode: 020202

HEAD OF SESSION: Mohammed WAHEEB

Authors	Affiliation	Presentation Title
Sanjida NOUSIN Rafsun RAHMAN Md Norim BHUYAN Md Nasir UDDIN Sajib HASAN	*St. Francis College*	Artificial Intelligence for Cancer Diagnosis and Prognosis
Md Iqbal HOSSAIN Md Bani AMIN Aspiya AKTER Rakib UL HASAN	*St. Francis College*	Artificial Intelligence and Its Impact on Business and Society
El Kammaa AHMED Benksim Abdelhafid Abou Elhassan TAOUFIK Nejmi HICHAM	*Cadi Ayyad University*	Knowledge, Attitudes, And Practices Regarding Cardiopulmonary Resuscitation Among Healthcare Professionals In Marrakech, Morocco: A Cross-Sectional Study of Associated Factors
Tanvi Premchandani Mohammad Qutub Milind Umekar Amol Tatode Rahmudin khan	*Smt. kishoritai Bhoyar College of Pharmacy*	Vitamin B12 Deficiency–Associated Cognitive Dysfunction: Pathophysiological Mechanisms, Clinical Evidence, and Therapeutic Approaches
Umar Ismail UMAR Mohammed Ishaq MOHAMMED Tijjani Hadiza BELLO	*Abubakar Tafawa Balewa University*	Information and Communication Technology Adoption in Real Estate Practice: Implications for Sustainable Development in Jos Metropolis, Nigeria
NURUDDEEN Ibrahim MOHAMMED Ishaq Mohammed IROAGANACHI, Nneoma VIOLET	*Abubakar Tafawa Balewa University*	Exploring the innovative housing finance strategies in ecofriendly real estate development in Abuja, Nigeria
Ioana ARDELEAN Ion PETRE Florina BULEU Narcisa Carmen MLADIN Elena Ramona DRAGOMIR Maryam KRROSHEN Laurantiu Cezar TOMESCU Izabella PETRE	*University of Medicine and Pharmacy Timisoara*	Maternal Zinc Status During Pregnancy: Implications for Anemia and Gestational Health
Mohammed WAHEEB	*Queen Rania Faculty of Archaeology*	Environmental Archaeology in Jordan: How the Environment Shaped Ancient Civilizations
Tiberiu BULEU Sorin BURLICA Daian Ionel POPA Roxana FURAU Florina BULEU Ion PETRE	*University of Medicine and Pharmacy Timisoara*	Menopausal Symptom Burden as a Healthcare Priority: A Questionnaire-Based Assessment of Women's Care Needs

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02.09.2026 / ONLINE / SESSION-2 / HALL-1

Budapest Local Time: 11:30-13:30 Ankara Local Time: 12:30-14:30

Zoom Meeting ID: 860 5266 6988 / Zoom Passcode: 020202

HEAD OF SESSION: Prof. Dr. Özlem ÖNAL AŞÇI

Authors	Affiliation	Presentation Title
Yakup POLAT Burhanettin İMRAK Salih KAFKAS	*Cukurova University*	Evaluation of The Biochemical And Antioxidant Properties of Cultivated And Wild Jujube (*Ziziphus Jujuba* Mill.) Genotypes
Yakup POLAT Nermin KALAY SARI Muhammet Ali GÜNDEŞLİ Salih KAFKAS	*Cukurova University*	Evaluation of Fruit Quality Characteristics of Some Pitaya (*Hylocereus* Spp.) Cultivars Grown İn The Mersin Region
Özlem ÖNAL AŞCI	*Ordu University*	The Effect Of Low Temperature On Seed Germination In Some Perennial Forage Legumes
Özlem ÖNAL AŞCI Eyyüp ALTINDAL	*Ordu University*	Pasture Improvement In Transitional Climate Conditions: The Akbudak Village Example
Adem KARCI	*Kahramanmaras Istiklal University*	Fatigue Damage Initiation And Propagation In Fiber Reinforced Carbon/Epoxy Composites and 2024-T3 Al Alloys Used In Aircraft
Hatice DAĞHAN Onur GÜLTEKİN	*Eskisehir Osmangazi University*	The Use Of Fruit And Vegetable Waste Compost In Basil (*Ocimum Basilicum* L.) Plant Cultivation And Its Effects On Plant Growth
Yağmur KIVRAK Serkan YILMAZSÖNMEZ Taha SİVRİKAYA	*Marshall Paints and Varnishes Industry Inc.*	Comparative Analysis of The Cleanability And Photo-Oxidative Degradation Performance of Styrene And Pure Acrylic Emulsions
Eren GÜVEN	*Coskunoz Metal Form Industry and Trade Inc.*	Comparative Analysis of The Impact of Different Image Resolutions on Deep Learning-Based Small Object Detection Performance
Eren GÜVEN	*Coskunoz Metal Form Industry and Trade Inc.*	Experimental Investigation of Thermal Performance of Btms Units In High-Volume Battery Packs At Specific Power (Kw) Levels

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02.09.2026 / ONLINE / SESSION-2 / HALL-2

Budapest Local Time: 11:30-13:30 Ankara Local Time: 12:30-14:30

Zoom Meeting ID: 860 5266 6988 / Zoom Passcode: 020202

HEAD OF SESSION: Prof. Dr. Erdem GÜLÜMSER

Authors	Affiliation	Presentation Title
Ayşin ÇİFTCİ EKİCİ Elif AYDIN Rıza ATAV	*Ozsar Textile Knitted Fabric Industry and Trade Ltd. Co*	Imparting Aromatherapy Properties to Viscose Fabrics Through Chemical Modification With Dendrimers
Orhan ERMETİN Ömer Faruk KARACA	*Yozgat Bozok Üniversitesi*	Assessment Of Animal Welfare In Dairy Cattle Using Artificial Intelligence And Computer Vision Technologies
Orhan ERMETİN Seyit UĞUZ	*Yozgat Bozok Üniversitesi*	Mechanical Ventilation And Cooling Technologies For Mitigating Heat Stress İn Dairy Cattle Housing
Orhan ERMETİN Ertuğrul KUL	*Yozgat Bozok Üniversitesi*	Importance Of Dry Period Management For Mastitis Prevention In Dairy Cattle
Hasan Üstün BAŞARAN Aytekin Duranay	*Izmir Katip Celebi University*	Waste Heat Recovery Technologies For Energy-Efficient And Decarbonized Marine Vessels: A Review
Özlem KILIÇ BÜYÜKKURT	*Osmaniye Korkut Ata University*	Effects of Germination on Aroma Profile And Aroma-Active Compounds in Cereals And Legumes: A Review
Hayriye ŞENTÜRK ÇİFTÇİ	*Istanbul University*	A Bioinformatics Perspective on The Potential Role of The Cyp2c19 Gene In Pharmacogenetics
Uğur BAŞARAN Erdem GÜLÜMSER	*Yozgat Bozok University*	Effects of Different Concentrations of Hop (*Humulus Lupulus* L.) Extract On Seed Germination And Early Seedling Growth of Forage Pea (*Pisum Sativum* L.)
Erdem GÜLÜMSER Uğur BAŞARAN	*Bilecik Seyh Edebali University*	FORAGE YIELD AND QUALITY OF GRASS PEA (Lathyrus sativus L.) AND OAT (Avena sativa L.) MIXTURES GROWN UNDER SUMMER CONDITIONS

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02.09.2026 / ONLINE / SESSION-2 / HALL-3

Budapest Local Time: 11:30-13:30 Ankara Local Time: 12:30-14:30

Zoom Meeting ID: 860 5266 6988 / Zoom Passcode: 020202

HEAD OF SESSION: Vatamanita MARIANA

Authors	Affiliation	Presentation Title
Mbulu N.S Nwadike B.I Gegelesho C.	*University of Ibadan*	Bacterial Degradation of Low Density Polyethylene
Arup Singha ROY Farhatul Hasan SHATU Md. Rafiqul ISLAM	*Jashore University of Science and Technology,*	Shared Genetic Architecture And Causal Effects of Circulating Vitamin D on Cardiometabolic Diseases: Evidence From Linkage Disequilibrium Score Regression And Mendelian Randomization
Vatamanita MARIANA	*University of European Political and Economic Science*	Protection of Human Life And Health In The Context of Construction-Related Offenses: An Interdisciplinary Approach
Vatamanita MARIANA	*University of European Political and Economic Science*	Role of Public Health Authorities in Preventing Construction- Related Offenses in The Republic Of Moldova
Abubakar Saidu ALIERO	*Federal University Birnin Kebbi*	Firth's Penalized-Likelihood Regression for Handling Separation in Hypertension Risk Factor Data: Evidence from Birnin Kebbi, Nigeria
Helal UDDIN Soham Biren KATLARIWALA Md Sohag AHASAN Rehana Khanam MOWSUMI	*Hajee Mohammad Danesh Science and Technology University*	Advanced Engineering Solutions And Economic Assessment For Next-Generation Healthcare Systems
Amina SANI	*Fedral University Dutsinma*	Solvent-Departdent Antibacterial Activity Of Turtemic (Curcuma Longa) Extracts Against Klebsiella Pneumoniae And Staphylococcus Aureus
Helal UDDIN Md Sohag AHASAN Rehana Khanam MOWSUMI Md. Rasel AHMED Zaryab BASHARAT	*Hajee Mohammad Danesh Science and Technology University*	Advanced Engineering Solutions For Next-Generation Healthcare And Health Science Applications
Boyiako Hgnonamede BERNADETTE Elsa Maria SALVADOR	*Eduardo Mondlane University*	Enhancing Nutritional Quality Of Cassava Mahewu: A Functional Beverage To Combat Micronutrient Deficiencies

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02.09.2026 / ONLINE / SESSION-2 / HALL-4

Budapest Local Time: 11:30-13:30 Ankara Local Time: 12:30-14:30

Zoom Meeting ID: 860 5266 6988 / Zoom Passcode: 020202

HEAD OF SESSION: Rutuja Vishram DESHPANDE

Authors	Affiliation	Presentation Title
Hicham RAHMI Ben Yamine MALLOUKI Fatiha CHIGR Mohamed NAJIMI Anas HAMDANI Atman ADIBA	*Sultan Moulay Slimane University*	Dose-Related Differences in Hematological and Biochemical Markers Among Cannabis–Tobacco Users in Morocco
Gulnar ATAKİSHİYEVA Sevinc MUKHTAROVA Sima MUSAYEVA Ilhama HAMDULLAYEVA Nigar AHMEDOVA Irada SHİKHALİYEVA Gulnara BABAYEVA	*Baku State University*	Comparative Analysis of Gi Absorption Properties of Three Hydrazone Derivatives Using The Swissadme Platform
Gulnar ATAKİSHİYEVA Sevinç MUHTAROVA Shukufa EYVAZOVA Naila VEYSOVA Shafiga İBRAHİMOVA Ayten QAJAR Teymur SADIXLI	*Baku State University*	Molecular Docking Investigation of (E)-4-Hydroxy-N′-(3-Iodo-5- Methoxy-4-((5-Nitrofuran-2-Yl)Oxy) Benzylidene) Benzohydrazide Against The 4kfg Protein Target
Badria Mahmoud ABDUSSALAM Rabiu Musa ISAH	*National University of Malaysia*	Prevalence of Malaria Infection During Pregnancy: A Systematic Literature Review
Sule MUHAMMAD	*Federal University Gusau*	Climate Change Awareness And Sustainability Practices Among Undergraduate Students of Federal University Gusau, Zamfara State, Nigeria
Emine SEYDAMETOVA	*Gyeongsang National University*	Biomedical Applications of Fucosylated Human Milk Oligosaccharides
Mir-Hassan MOOSAVY	*University of Tabriz*	Beyond The Final Product: Rethinking Food Hygiene And Quality Control Through A One Health Lens
Rutuja Vishram DESHPANDE	*Savitribai Phule Pune University*	Does Culture shape sustainable AI Regulation? A Comparative Analysis of The EU, India And China through Hofstede's Cultural Dimensions.
Rutuja Vishram DESHPANDE	*Savitribai Phule Pune University*	Does Culture shape sustainable AI Regulation? A Comparative Analysis of The EU, India And China through Hofstede's Cultural Dimensions.

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02.09.2026 / ONLINE / SESSION-2 / HALL-5

Budapest Local Time: 11:30-13:30 Ankara Local Time: 12:30-14:30

Zoom Meeting ID: 860 5266 6988 / Zoom Passcode: 020202

HEAD OF SESSION: Muhammad IMRAN

Authors	Affiliation	Presentation Title
LAGRINI Ismail BENCHEIKH Mohamed	Hassan II University of Casablanca,	Impact of Flattening Filter Removal and Secondary Collimator on the Energetic Properties of a 6 MV Photon Beam Using Monte Carlo Simulation
Okebaram, Sunday Moses	Michael Okpara University of Agriculture University Umudike.	Managing The Green Transition in Nigeria: A Theoretical Review of Oil & Amp; Gas, And Solar Energy Pathways
Muhammad IMRAN	University of Veterinary and Animal Sciences,	From Smog Awareness to Protective Action: How Information Trust and Risk Perception Shape Health Responses in Lahore
Shahriar Hasan Mridha RATUL Latifa SULTANA K. M. Shakik Ahmed WALID Haimonty SARKER Moukuri MOHIM Mahjabin Tamanna MOURY S M Monirul ISLAM Arafat CHOWDHURY	Comilla University	Urban Development, Seismic Vulnerability and Public Health Resilience: Assessing Earthquake Risk in Dhaka, Bangladesh
Ummy RUBAB Muhammad IBRAHIM Irfa SAKANDAR	Biskra University,	Click Chemistry-Mediated Synthesis of Triazole Based Scaffolds: Spectroscopic Characterization And Biological Evaluation
Dekhili NOURELHOUDA Telli ABDELMOUTIA	Biskra University,	A Deep Learning Algorithms for Intelligent Mineral Exploration
Sunil AGRAWAL	People's University,	A Study of AI and Automated Decision-making in Marketing as well as Algorithmic Accountability.
M. JAYA KUMAR JACOB P. Brahmaji Rao	Hebrew Open University,	Holiness and Nature
N. MUNIYAPPAN K. PAPPATHI	Saraswathi Narayanan College,	Biogenic Synthesis and Characterization of Curcumin Loaded Gold@Chitosan Nanoparticles: Multifunctional Agent for Enhanced Drug Delivery and Therapeutic Efficacy

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02.09.2026 / ONLINE / SESSION-3 / HALL-1

Budapest Local Time: 14:00-16:00 Ankara Local Time: 15:00-17:00

Zoom Meeting ID: 860 5266 6988 / Zoom Passcode: 020202

HEAD OF SESSION: Elnara MAMMADOVA

Authors	Affiliation	Presentation Title
Oluwakemi Racheal OSHINOWO Moses Adeolu AGOI Christiana Toyin ODUWOLE Adebayo Samuel ADEOGUN	*Lagos State University of Education*	Intelligent Educational Management for Metaverse-Enabled Learning: Implications for Computer Science Education
Ravana GULIYEVA Nigar ALIYEVA Elnara MAMMADOVA Nilufar BAYRAMLI Nasimi GIYASOV Milana AKİFLİ Garatel RUSTAMOVA	*Baku State University*	Impact of Academic Pressure on Adolescent Mental Health
Elnara MAMMADOVA	*Baku State University*	The Impact of Management Process Automation on The Speed and Quality of Managerial Decision-Making In Business Organizations
Gheorghe GIURGIU Manole COJOCARU	*Deniplant-Aide Sante Medical Center*	What We know about Psoriasis so far?
Adegun ADEWALE Paul HARUNA	*Federal University of Technology*	Application of Architectural Strategies ın The Design of Trailers Rest Hub In Mokwa, Niger State
Elnara SHIRINOVA	*Baku State University*	Study of The Sorption Kinetics of Cu(Ii) Ions By The Sodium Salt of A Maleic Acid–Styrene–Allyl Propionate Terpolymer
Rihan ERZEN Meliha UZUN	*Şırnak University*	Digital Fitness Culture and Wellness: The Role of Social Media-Based Exercise Content in Physical and Psychological Well-Being
Güneş SAKIN Meliha UZUN	*Şırnak University*	Empowerment Through Sport: The Role of Sport in Promoting Independent Living and Social Participation Among Individuals with Special Needs

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02.09.2026 / ONLINE / SESSION-3 / HALL-2

Budapest Local Time: 14:00-16:00 Ankara Local Time: 15:00-17:00

Zoom Meeting ID: 860 5266 6988 / Zoom Passcode: 020202

HEAD OF SESSION: Bledar KRAJA

Authors	Affiliation	Presentation Title
Ion PETRE Flavia BARNA Miruna Lucia NACHESCU Razvan BOBORA Daian Ionel POPA Tiberiu BULEU Cristian PETRE	*"Victor Babes" University of Medicine and Pharmacy Timisoara*	Machine Learning–Based Assessment of Hematologic Toxicity During Chemoradiotherapy for Stage III Cervical Cancer
Usman Kris Joko SUHARJO Tunjung PAMEKAS Angela SAFUTRY	*University of Bengkulu*	Inducing The Formation of Solo Garlic Bulb At Low Elevation of Indonesia by Appyling Plant Growth Regulators on Vernilized Seed Materials
Alemu MITIKU Mollalgn HAILE Zenaw ASNAKE	*Bahir Dar University*	Some Fixed Points of Enriched Jaggi-Dass Type Contractions By Krasnoselskii Iterative Method In Banach Spaces
Tunjung PAMEKAS Sempurna GINTING Usman Kris Joko SUHARJO	*University of Bengkulu*	Evaluation of *Trichoderma* Sp. Metabolite Concentrations Against Basal Stem Rot Disease In Oil Palm Seedlings In The Main Nursery
Bledar KRAJA	*University of Medicine Tirana*	Dietary Patterns In Albania: Between The Mediterranean Tradition And Nutritional Transition
Adepoju Moses DAMILOLA	*Federal University of Technology, Minna*	Green Architecture Features And Perceived Users' Satisfaction In Nigeria's Resort Facilities
Christopher Nnamdi FRANCIS Isa Bala MOHAMMAD	*Federal University of Technology Minna,*	Exploration of Sukur Indigeneous Climatic Adaptation Strategies In Residential Buildings in Adamawa State, Nigeria
Ushahemba Benjamin HIME Gafari Adebisi OLABAMIJI	*Federal University of Technology Minna*	Indigenous Building Materials in Makurdi, Nigeria: Availability and Implications for Sustainable Architecture

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02.09.2026 / ONLINE / SESSION-3 / HALL-3

Budapest Local Time: 14:00-16:00 Ankara Local Time: 15:00-17:00

Zoom Meeting ID: 860 5266 6988 / Zoom Passcode: 020202

HEAD OF SESSION: Atharva Sanjay NAIK

Authors	Affiliation	Presentation Title
Olayemi Felicia AMOLE Mordecia GANA Oluwafemi Adebayo OYEWOLE	*Federal University of Technology*	Screening and Isolation of Methionine-Producing Bacteria and Their Fermentation of Enzymatically Hydrolyzed Agricultural Wastes
Olayemi Felicia AMOLE Mordecia GANA Oluwafemi Adebayo OYEWOLE	*Federal University of Technology*	Screening and Isolation of Methionine-Producing Bacteria and Their Fermentation of Enzymatically Hydrolyzed Agricultural Wastes
Md. Sabit HOSSAN Maruf Hasan KHAN Md. Ratul HASAN Sukalyan Kumar KUNDU	*Jahangirnagar University*	In Silico Drug Discovery of Bangladeshi Medicinal Plant-Derived Phytochemicals Targeting the MEK1/ERK2 Signaling Pathway in Lung Cancer
Muhammad Safi ASLAM Anum Arif BUTT Haziq MEHMOOD Maria PANAGOTI	*University of Management and Technology*	Exploration of Sociological and Urban Determinants of Happiness among Middle-aged Urban Adults using Grounded Theory Approach
V. Ananthaswamy M. Shruthi	*Affiliated to Madurai Kamaraj University*	Semi-Analytical Investigation of a Non-linear Initial Value Problem in a Cancer Model
Jegamohanan ANUSHA Paramasivan SIVAKUMAR S. R. DHARSHINI	*S.I.V.E.T. College*	Histopathological and Behavioural Recovery of Zebrafish (Danio rerio) Following Adsorption-Based Detoxification of Auramine O Dye: A Sustainable Approach to Environmental Health.
Mbuotidem D. DICK Emem Okon IKPE Gabriel Abraham BALA	*Akwa Ibom State Polytechnic*	Integrated ERT-SRT and Machine Learning for Engineering Site Characterization
Atharva Sanjay NAIK	*Legal practitioner under state bar council*	Environmental Governance of Real Estate and Urban Development: A Comparative Analysis of India, Singapore and the United Kingdom
Poonam YADAV Sunil KUMAR	*Indira Gandhi University*	Compost Based Electrochemical Energy Storage

(All speakers required to be connected to the session 10 min before the session starts)
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02.09.2026 / ONLINE / SESSION-3 / HALL-4

Budapest Local Time: 14:00-16:00 Ankara Local Time: 15:00-17:00

Zoom Meeting ID: 860 5266 6988 / Zoom Passcode: 020202

HEAD OF SESSION: Yusuf SALEH

Authors	Affiliation	Presentation Title
Yusuf SALEH	Federal University of Technoly Ilaro	Vaccination and Economic Growth In Nigeria
Mouad LAZRAK Maryam MIROUCH Ghita Ait BADDI Ayour JAMAL Dhin IKRAM Soukaina KAOUI Chaouki ZINEB Chebli BOUCHRA	Ibn Zohr University	Compost-Derived Humic Substances as Green Precursors for Biomedical Nanoparticle Synthesis and Nanomedicine Applications
Aminu Ibrahim BELLO Jabir Hamisu ABDULLAHI Idris ABUBAKAR Maryam Yusuf BELLO	Umaru Musa Yaradu'a University Katsina	Antimicrobial Resistance at the Human–Animal–Environment Interface: Emerging Threats, Transmission Pathways and One Health Control Strategies
Abdullahi NASIR Aliyu Ibrahim YARADUA Aminu IDI Abubakar SANI BK.	Umaru Musa Yaradu'a University	Pollution Indices and Health Risk Assessment of Heavy Metals in an Urban Playground Soil from Katsina State, North-Western Nigeria
Muneerah al OTAIBI Nirvana Abdelrahman GHEITH Maram Ahmed BANKHAR	King Abdulaziz University	Assessing awareness,self-reporting practice and barriers to incident reporting:across-sectional study among nurses
Vardhana JANAKIRAMAN SriNandhini Tharun B N. K. Udaya PRAKASH	School of Sciences- Life Sciences	Assessment of Sugarcane Bagasse derived Bioash for the Removal of Methyl Violet and Crystal Violet Dyes
Simon P Payrs MBBS Mtrauma FRACS	Armadale Kelmscott Memorial Hospital	Rothia mucilaginosa Peritonitis in an otherwise health patient: A Case Report
Egzona KRASNIQI Ilir MAZREKU	University of Prishtina	Effect of antiepileptic drugs in cognitive functions, anxiety, and hematological parameters in mice
Muhammad USAMA Mahwish SALMAN Muhammad AZEEM	Government College University Faisalabad	Integrating Computational Biology and Microbial Metabolites for Climate- Resilient Plant Growth

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02.09.2026 / ONLINE / SESSION-3 / HALL-5

Budapest Local Time: 14:00-16:00 Ankara Local Time: 15:00-17:00

Zoom Meeting ID: 860 5266 6988 / Zoom Passcode: 020202

HEAD OF SESSION: Amr FARHAN

Authors	Affiliation	Presentation Title
Amr FARHAN Abduladeem G.M. AL-SELWİ Adeb A.S.A. ALMAAMARİ Ayoub ECHCHAHED Badreddine LABAKOUM Amr R. HAİDAR Aissam LYAZİDİ	AL Rowad University	Development of a Metamaterial-Based Microwave Sensor for Non-Invasive and Non-Contact Blood Glucose Monitoring
Imane NOURANI Lydia HELEILI Abdelmalek Aymen BRAHIMI	University hospital of Batna	Evaluation of a Seasonal Influenza Vaccination Campaign in Primary Healthcare Settings in Algeria: The Experience of El Madher District, Batna, 2025–2026
Sulaiman Muhammad Usman Lawal Usman Mudassir Badamasi Fatima Abdullahi Hari	National Biotechnology Research And Development Agency	Microplastic Contamination In Clarias Gariepinus And Oreochromis Niloticus Fishes And Assessment of Potential Health Risks Associated With Their Consumption From Mairuwa Reservoir, Funtua, Katsina State, Northwestern Nigeria
Lansine DİAKİTÉ Abdeljalil ELMAHDAOUİ Zineb LACHHAB Zahra SOKAR	Cadi Ayyad University	Protective effects of Acacia raddiana gum Against urethane-induced pulmonary carcinogenesis in rats
Youssra ECH-CHAHDI Hicham ZAITAN Fouad KHALIL	Sidi Mohamed Ben Abdellah University	Computational Discovery of Novel c-Met Inhibitors for Prostate Cancer through an Integrated Structure- and Ligand-Based Drug Design Approach
Idris, M Auta, T Yakubu, A Adamu, M. B Mamuda, A. M.	National Biotechnology Research, and Development Agency	Interactions Of Some Physicochemical Parameters And Sediment Heavy Metals With Snails Species In Ajiwa Reservoir
HARIBOU Nissrine NFISSI Kawtar	Sidi Mohammed Ben Abdellah University	Green Ambitions, Industrial Pressures: The Tension Between Economic Development and Environmental Protection in Morocco
POROSNICU Gianina Vera	Attorney at Law, Iași Bar Association	The Right of Victims of Medical Malpractice to Obtain Compensation
Jatinkumar Bhimjibhai KOTADIYA	Atmiya University	An Ai-Driven Multilingual Sentiment Analysis Framework For Intelligent Healthcare Feedback And Patient Experience Assessment

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03.09.2026 / ONLINE / SESSION-1 / HALL-1

Budapest Local Time: 09:00-11:00 Ankara Local Time: 10:00-12:00

Zoom Meeting ID: 860 5266 6988 / Zoom Passcode: 020202

HEAD OF SESSION: İbrahim SÖNMEZ

Authors	Affiliation	Presentation Title
Kamil SARPKAYA İbrahim SÖNMEZ	*Atatürk Central Horticultural Research Institute*	Management Of Biotic Stress In Crops With Pgpr: Fungal Pathogens, Viruses And Plant-Parasitic Nematodes
İbrahim SÖNMEZ Kamil SARPKAYA	*Atatürk Central Horticultural Research Institute*	Heavy Metal Stress In Vegetable Crops And Pgpr-Assisted Bioremediation: Physiological Mechanisms, Food Safety And Practical Prospects
Fatma KAYAÇETİN Nilüfer KOÇAK ŞAHİN	*Ankara University*	Effects of PGPR Applications on Plant Growth, Yield, and Stress Tolerance in Brassica napus L. Cultivation
Nilüfer KOÇAK ŞAHİN Fatma KAYAÇETİN	*Ankara University*	Relationships among Leaf Mineral Elements in Seaweed-Treated Peanut under Salinity Stress: A Correlation Analysis
Mehmet Ali KAYA	*MEB*	Climate, Gender, And Mastery: Ecofeminist Perspectives On Stanley Robinson's Forty Signs Of Rain And Michael Crichton's State Of Fear
Ayşe Burcu ATALAY	*Kahramanmaraş Istıklal University*	From Phytochemical Characterization To Functional Food Applications: A Systematic Review Of Dandelion (*Taraxacum officinale*) Research In Food Science
Muhammet Ali GÜNDEŞLİ	*Kahramanmaraş İstiklal University*	Impacts of Climate Change on Fruit Growing and Sustainable Production Approaches
Muhammet Ali GÜNDEŞLİ	*Kahramanmaraş İstiklal University*	The Role of Smart Agricultural Technologies in the Process of Adapting to Climate Change in Sustainable Fruit Growing
Murat MANAV	*Kahramanmaraş Sütcü İmam University*	Therapeutic Potential of Bioactive Compounds Found in Medicinal Leech Saliva
Murat MANAV	*Kahramanmaraş Sütcü İmam University*	Nutritional Characteristics of Medicinal Leeches: A General Review

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03.09.2026 / ONLINE / SESSION-1 / HALL-3

Budapest Local Time: 09:00-11:00 Ankara Local Time: 10:00-12:00

Zoom Meeting ID: 860 5266 6988 / Zoom Passcode: 020202

HEAD OF SESSION: Darkaoui Najoua

Authors	Affiliation	Presentation Title
Helal UDDIN Md. Ruhul AMIN Md Sohag AHASAN Nishat TASNIM Afsana Akther ERIN Md. Rasel AHMED Kazi Md. Mehedi HASAN Khalid Shaifullah MAHMUD Zaryab BASHARAT Rehana Khanam MOWSUMI Jannatun NAIMA Basmalaa Ahmed THABET	*Hajee Mohammad Danesh Science and Technology University*	Next-Generation Sustainable Healthcare Infrastructure: A Life-Cycle Assessment (LCA) Approach to Reducing Environmental Impacts
DARKAOUI Najoua	*Sidi Mohamed Ben Abdellah University*	Eco-epidemiology and spatio-temporal distribution of sand flies (Diptera: *Psychodidae*) in the city of Fez: Risk factor evaluation of cutaneous leishmaniasis
El Ghizi SARA Hssaissoune SLIMANE El Bouch MOHAMMED Sadik MOHAMMED Hasnaoui MUSTAPHA	*University of Sultan Moulay Slimane*	Heavy Metal Toxicity and Sediment Quality Assessment in Lake Dayet Er- Roumi (Morocco): Integrated Environmental Indices and Multivariate Statistics
Umesh JAIN Divya THAKARE	*Research Scholar at SNJB Shriman Sureshdada Jain college of Pharmacy*	Integrated In Silico and Preclinical Evaluation of Morinda citrifolia Fruit Extract for Anxiolytic Activity: A Network Pharmacology and Elevated Plus Maze Study
El Ghizi SARA Hssaissoune SLIMANE El Bouch MOHAMMED Sadik MOHAMMED Hasnaoui MUSTAPHA	*University of Sultan Moulay Slimane*	Heavy Metal Toxicity and Sediment Quality Assessment in Lake Dayet Er- Roumi (Morocco): Integrated Environmental Indices and Multivariate Statistics
S. SIVASANKARI V. ANANTHASWAMY M. SUBHA	*The Madura College*	Application of New Approximate Analytical Method For Solving Oscillator Equations In Physical Sciences
J. Anantha JOTHI V.ANANTHASWAMY M. SUBHA	*The Madura College*	A Mathematical analysis of dynamic SIR epidemiological model
Muhammad RIZWAN Farrah DEEBA Anas Sarwar QURESHI Muhammad Muazzam IQBAL	*The Madura College*	A Study on Vitamin Supplementation in Subclinical Mastitis in Buffaloes
Kausar RABI'U Yusuf ADAMU Aminu Ibrahim BELLO Salihu SALISU Yahaya Yunusa RIKO	*Umaru Musa Yar'adua University*	The Human Gut Microbiome as a Reservoir of Antimicrobial Resistance Genes: Mechanisms of Resistance Development and Dissemination

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03.09.2026 / ONLINE / SESSION-1 / HALL-4

Budapest Local Time: 09:00-11:00 Ankara Local Time: 10:00-12:00

Zoom Meeting ID: 860 5266 6988 / Zoom Passcode: 020202

HEAD OF SESSION: Addra, NOAH AGBO

Authors	Affiliation	Presentation Title
Hassan BENCHELH Soulaiman HARFOUF El mostapha ELMAKKAOUI Karim NADIR Hicham ATATRI Abdelhak MOUSTAINE	*Abdelmalek Essaâdi University*	Agreement Between Four Vopeak Estimation Equations and Health-Related Fitness Classification in Adolescents: LMS Reference Curves from Kénitra, Morocco
Mande, U.U Suleiman, Z.A Hassan, S.W Nasir, H.N	*Umaru Musa Yar'adua University*	Anti-Diarrhoeal And Toxicological Properties of Root Extract of Cassia Singueana
Maroua RIAD Wissal LAAJALI Ahmad AL-SHAMI Jamal MABROUKI	*Mohammed V University*	Liquid Biopsy In Breast Cancer: Emerging Biomarkers For Early Detection And Treatment Monitoring
Florence Ohunene Omuya	*Federal University Lokoja*	Curriculum Reform For 21 St Century Skills And Employability In Educational Administration
Addra, NOAH AGBO	*Federal University Lokoja*	Nurse's Legal Knowledge and Compliance with Informed Consent Standards: A Comparative Study of Federal University Teaching Hospital, Lafia And Federal Medical Centre, Keffi, Nasarawa State, Nigeria
ALI, M. E., YUSUF, Z. A., AKINNAGBE, E. S., ALIYU, A. A. UMAR, A. K. AQIBA, R. U.	*National Biotechnology Research and Development Agency*	Performance of Clarias Gariepinus (Burchell, 1822) Hatchlings Fed Varying Levels of Dietary Beetroot Powder
Dharmendrakumar Jayantilal AMBANI	*Harivandana College*	An Ai-Driven Hybrid Sentiment Analysis Framework for Intelligent Healthcare Feedback Classification Using Machine Learning and Transformer Models
Hetal Pravinsinh JADEJA	*Harivandana College*	An Enhanced Hybrid Transformer-Based Sentiment Analysis Framework for Medical and Health-Related Online Patient Feedback
Sweety MITRA Pushpa VISHWAKARMA Hina VAISH	*CSJM University*	Digital Applications for the Six-Minute Walk Test in Normal Adults: A Protocol of Systematic Review

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03.09.2026 / ONLINE / SESSION-1 / HALL-5

Budapest Local Time: 09:00-11:00 Ankara Local Time: 10:00-12:00

Zoom Meeting ID: 860 5266 6988 / Zoom Passcode: 020202

HEAD OF SESSION: Jamila ZAYYANA MAIMAJE

Authors	Affiliation	Presentation Title
Jamila ZAYYANA MAIMAJE	Katsina State College Of Health Sciences And Technology Katsina	Effects of Aqueous Extract of *Cinnamomum Verum* on Gastric Ulcers Induced by Long-Term Low-Dose Aspirin In Male Wistar Rats
Yakubu, A I. M Magami., Idris, M M. A Garga Bawa, Y. M Bako. I Adamu, M. B HASSAN N. M Abdulkarim Y. M Mamuda, A. M Daniyan, A. M. Garba, I.	National Biotechnology Research, and Development Agency	Synergistic Antidiabetic Activity of *Cinnamomum Verum* And Annona Squamosa Ethanolic Leave Extracts In Streptozotocin Induced Diabetic Wistar Rats
Yakubu, A I. M Magami., Idris, M M. A Garga Bawa, Y. M Bako. I Adamu, M. B HASSAN N. M Abdulkarim Y. M Mamuda, A. M Daniyan, A. M. Garba, I.	National Biotechnology Research, and Development Agency	Synergistic Antidiabetic Activity of *Cinnamomum Verum* and *Annona Squamosa* Ethanolic Leave Extracts in Streptozotocin Induced Diabetic Wistar Rats
DAHMANI Maroua ANTRAOUI Ilyas Ali Khettabi	University Mohamed I.	Interference-Enhanced Acoustic Gas Sensing for Environmental Monitoring and Safety Applications
Isaiah Baba MUSA Osuagwu Chioma ONYINYECHI Saadatu Muhammad Ahmad ISAH Sanda Usman UMAR	Federal University of Technology	Harnessing Indigenous Metal-Resistant Bacteria for Plant Growth Promotion and Sustainable Remediation of Mining-Impacted Soils
Enu AGBOR AGBOR John ADOLE	Federal University of Lafia Nasarawa State	Medicine and Surgery: Healing Narratives in African Literature
S.PUNITHA V.ANANTHASWAMY	The Madura College,	A semi analytical study on entropy generation of Eyring- Powell fluid flow through a Microchannel
Jamila ZAYYANA MAIMAJE Asiya SADA ABDULLAHI	Katsina State College Of Health Sciences And Technology Katsina	Effects Of Aqueous Extract of *Cinnamomum Verum* On Gastric Ulcers Induced by Long-Term Low-Dose Aspirin In Male Wistar Rats
Boyiako BERNADETTE David-Abraham FOLUSHO Ibeogu Isaiah HENRY Mgbebu Patricia OGODO Alu collins NNAJI Fanou-Fogny NADIA Nnamani CATHERINE	Ebonyi State University	Effect of Maturity Stage on the Protein Content of Five Amaranthus Species

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03.09.2026 / ONLINE / SESSION-1 / HALL-6

Budapest Local Time: 09:00-11:00 Ankara Local Time: 10:00-12:00

Zoom Meeting ID: 860 5266 6988 / Zoom Passcode: 020202

HEAD OF SESSION: Anamika Basu

Authors	Affiliation	Presentation Title
Rakela Sehitaj Denada Selfo	*University of Vlora*	The Impact of Preoperative Nursing Education On Reducing Anxiety And Improving Postoperative Recovery In Surgical Patients
DAHMANE Thoraya KACI Zakia AROUS Ali KARAHACENE Taher HALLI Latifa	*Djilali Bounaama University*	Antifungal Profile of Flavonoid Extracts Obtained from the Leaves Thymus algeriensis Boiss. et Reut.
Anamika Basu Anasua Sarkar	*Gurudas College*	Network Pharmacology and Multi-Omics Profiling of Berberis vulgaris L. Alkaloids: Mapping Target Genes Across Complex Disease Networks
Ramona Elena DRAGOMIR Daniela Oana TOADER Ion PETRE Florina BULEU IZABELLA PETRE	*National Institute for Mother and Child Health "Alessandrescu-Rusescu"*	Beyond Vitamin D Deficiency: Cardiometabolic Predictors of Hypertensive Disorders in Pregnancy
Muhammad Salman Sadid Shahriyar Methila Farjana Tazwar Rahman Ashir Humaira Shabbir	*Abdul Wali Khan University Mardan*	Dose-Dependent Effects of Iron Chloride (Fecl) Stress On Seed Germination, Seedling Growth, And Biomass Accumulation In Wheat (*Triticum Aestivum* L.)
Tiberiu BULEU Sorin BURLICA Daian Ionel POPA Roxana FURAU Florina BULEU Ion PETRE	*"Victor Babes" University of Medicine and Pharmacy Timisoara,*	Beyond Hot Flushes: The Multidimensional Burden of Menopausal Symptoms and Implications for Women's Healthcare
Florina BULEU Ion PETRE Tiberiu BULEU Madalina SOROP Daian Ionel POPA Izabella PETRE	*"Victor Babes" University of Medicine and Pharmacy Timisoara*	Maternal Anemia and Interleukin-6 Profiles in COVID-19 Pregnancies Complicated by Hypertensive Disorders
Ioana ARDELEAN Ion PETRE Florina BULEU Narcisa Carmen MLADIN Elena Ramona DRAGOMIR Maryam KRROSHEN Laurantiu Cezar TOMESCU Izabella PETRE	*"Victor Babes" University of Medicine and Pharmacy Timisoara*	Maternal Zinc Status and Hematological Health During Pregnancy: Preliminary Insights into Micronutrient Vulnerability
Hooi Peng LIM Salim BACHOK Halimatul Sa'diah TALIB	*Politeknik Ibrahim Sultan*	Enhanced Mechanical and Thermal Properties of Alkali-Treated Coir Fibers Incorporated with Murraya Koenigii: A Comparative Study of Mono-layer and Tri-layer Biocomposites
İhsan Serkan VAROL	*Erciyes University*	Evaluation of Salt Tolerance in Annual Ryegrass (Lolium multiflorum L.) Cultivars during Germination and Seedling Development

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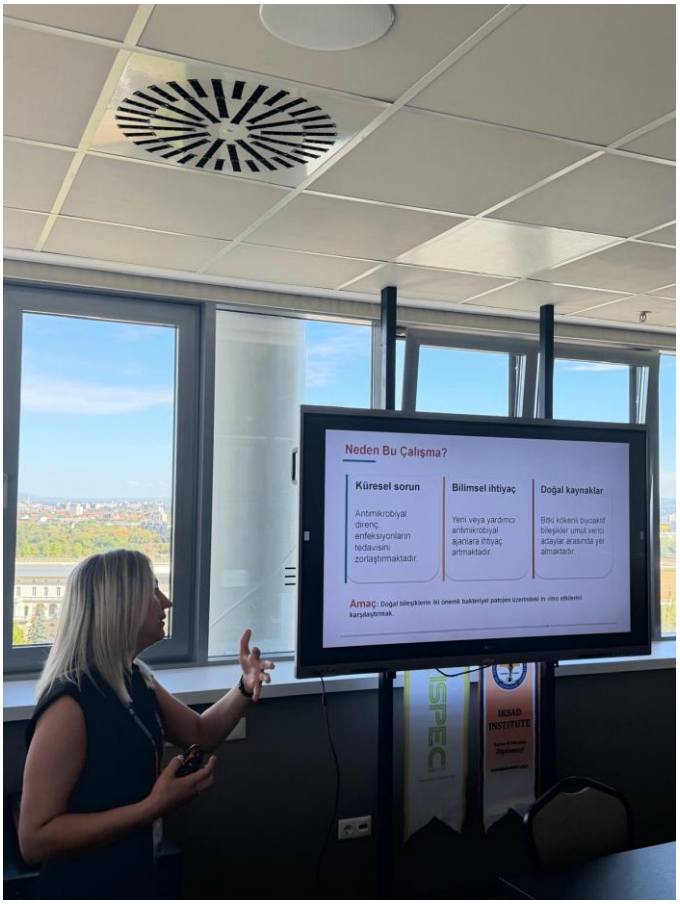





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SCIENTIFIC COOPERATION AND
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TAS1R2: kript epitelinde yaygın sitoplazmik immünreaktivite
C
d
100 µm
100 µm
TAS1R2
Kript epitel hücrelerinde yaygın sitoplazmik pozitiflik; stromal kompartman ve müsküler mukoza negatif
ISPEC


Neden Bu Çalışma?
Küresel sorun
Antimikrobiyal direnç enfeksiyonların tedavisini zorlaştırmaktadır.
Bilimsel ihtiyaç
Yeni veya yardımcı antimikrobiyal ajanlara ihtiyaç artmaktadır.
Doğal kaynaklar
Bitki kökenli biyoaktif bileşikler umut verici adaylar arasında yer almaktadır.
Amaç: Doğal bileşiklerin iki önemli bakteriyel patojen üzerindeki in vitro etkilerini karşılaştırmak.
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THE IMPORTANCE OF THE MAJOR CHEMICAL COMPONENTS IN THE ESSENTIAL OILS OF THREE SALVIA SPECIES ENDEMIC TO TURKIYE




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BAĞ TOPRAKLARINDAN İZOLE EDİLEN BAKTERİLERİN SİDEROFOR ÜRETİM POTANSİYELLERİNİN BELİRLENMESİ

DETERMINATION OF THE SIDEROPHORE PRODUCTION POTENTIAL OF ANTAGONISTIC BACTERIA ISOLATED FROM VINEYARD SOILS

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ÖZET
Bu çalışmada, Gaziantep, Mersin ve Osmaniye illerindeki asma rizosfer topraklarından izole edilen 156 aday antagonist bakterinin siderofor üretme kapasiteleri değerlendirilmiştir. Siderofor üreten bakteriler, topraktaki demiri (Fe) bitkiler tarafından kullanılabilir forma dönüştürerek bitki beslenmesini desteklemekte, aynı zamanda fitopatojenlerle demir rekabetine girerek biyolojik mücadeleye katkı sağlamaktadır. Bakteri izolatları, bağ rizosferi toprak örneklerinden seri seyreltme tekniği kullanılarak elde edildi. İzolatların siderofor üretim potansiyelleri, Chrome Azurol S (CAS) agar yöntemi kullanılarak belirlenmiş ve oluşan zon çaplarına göre siderofor indeksleri hesaplanmıştır. Yapılan değerlendirmeler sonucunda, 156 izolatın 32'sinin siderofor üretme yeteneğine sahip olduğu belirlenmiştir. İzolatların siderofor indeksleri 1.09–4.77 arasında değişmiş olup, en yüksek değerlere sırasıyla MecY1.2.3 (4.77), Y3.1 (3.16) ve MutT1.8.5 (2.36) kodlu izolatlar ulaşmıştır. Elde edilen sonuçlar, yüksek siderofor üretme kapasitesine sahip antagonist bakteri izolatlarının bağ hastalıklarının biyolojik mücadelesinde ve sürdürülebilir üzüm yetiştiriciliğinde potansiyel biyolojik mücadele elemanı olarak kullanılabileceğini göstermektedir. Bu çalışma, devam etmekte olan bir yüksek lisans tez çalışmasının ön bulgularını içermektedir.
Anahtar Kelimeler: *Vitis vinifera* L., Rizosfer, Bitki Gelişimini Teşvik Eden Bakteriler (PGPR), Sürdürülebilir Tarım, Biyolojik Mücadele,

ABSTRACT
This study evaluated the siderophore production capacities of 156 candidate antagonistic bacterial isolates obtained from vineyard rhizosphere soils collected in the provinces of Gaziantep, Mersin, and Osmaniye, Türkiye. Siderophore-producing bacteria promote plant nutrition by converting soil iron (Fe) into a plant-available form while contributing to biological control through competition with phytopathogens for iron. Bacterial isolates were obtained from vineyard rhizosphere soil samples using the serial dilution technique. The siderophore production potential of the isolates was determined using the Chrome Azurol S (CAS) agar assay, and siderophore indices were calculated based on the diameters of the orange halos formed around the bacterial colonies. Among the 156 isolates evaluated, 32 were found to be capable of producing siderophores. The siderophore index ranged from 1.09 to 4.77, with the highest values recorded for isolates MecY1.2.3 (4.77), Y3.1 (3.17), and MutT1.8.5 (2.36). These findings indicate that antagonistic bacterial isolates with high siderophore production capacity have considerable potential as biological control agents for the management of grapevine diseases and for promoting sustainable viticulture. This study presents the preliminary findings of an ongoing master's thesis.
Keywords: *Vitis vinifera* L., rhizosphere, Plant Growth-Promoting Rhizobacteria (PGPR), Sustainable Agriculture, Biological Control

MEYVE KALİTESİ VE HASAT SONRASI ÖMRÜN İYİLEŞTİRİLMESİNDE GENOM DÜZENLEME

GENOME EDITING FOR IMPROVING FRUIT QUALITY AND POSTHARVEST LIFE

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ÖZET

Genom düzenleme teknolojileri, uzun gençlik dönemleri, yüksek heterozigotluk, poliploidi ve karmaşık üreme biyolojisi ile karakterize edilen meyve türlerinde geleneksel ıslah yöntemlerine kıyasla hedefli ve hızlı iyileştirme sağlayan güçlü bir yaklaşım olarak öne çıkmaktadır. Mevcut genom düzenleme sistemleri arasında CRISPR/Cas teknolojileri meyve türlerinde en yaygın kullanılan araçlardır ve son yıllarda baz düzenleme, primer düzenleme, çoklu genom düzenleme ve transgen içermeyen düzenleme yaklaşımları bu teknolojinin uygulama potansiyelini daha da genişletmiştir. Güncel çalışmalar, genom düzenlemenin meyve olgunlaşması, raf ömrü, doku, besin içeriği, renk, aroma ve bozulmaya karşı direnç ile ilgili temel biyolojik süreçleri değiştirmek için kullanılabileceğini göstermiştir. Domateste, *RIN* ve *ALC* gibi olgunlaşmayla ilgili genlerin düzenlenmesi, olgunlaşma sürecini değiştirmek ve raf ömrünü uzatmakla ilişkilendirilirken, *PSY1*, *MYB12* ve *SGR1* genlerinin çoklu hedeflemesi, meyve renginin ve besin bileşiminin aynı anda iyileştirilebileceğini göstermiştir. Muzda, etilen biyosentezinde rol oynayan *MaACO1* geninin CRISPR/Cas9 kullanılarak düzenlenmesi, meyvenin raf ömrünü uzatmanın önemli bir örneğidir. Üzümde tartarik asit biyosenteziyle ilişkili *IdnDH* geninin düzenlenmesi, elma ve diğer meyvelerde enzimatik kahverengileşmeyi azaltmak için *PPO* ile ilgili genlerin düzenlenmesi ve turunçgillerde hastalık direncini artırmak için *CsLOB1* geninin hedeflenmesi, genom düzenlemenin meyve kalitesinin farklı bileşenlerinde kullanılabileceğini gösteren diğer çalışmalar arasındadır. Bu uygulamalar, hasat sonrası ömrün sadece olgunlaşmayı geciktirerek değil, aynı zamanda duyusal, besleyici ve ticari kalite özelliklerini eş zamanlı olarak koruyarak veya iyileştirerek de geliştirilebileceğini göstermektedir. Bununla birlikte, etkili transformasyon ve rejenerasyon sistemlerinin geliştirilmesi, pleiotropik etkiler, düzenleme verimliliği, transgen içermeyen düzenleme yöntemleri, mevzuata uyum ve tüketici kabulü, özellikle çok yıllık meyve türlerinde önemli sınırlamalar olmaya devam etmektedir. Gelecekte, hassas genom düzenleme, çoklu düzenleme, genomik yaklaşımlar ve gelişmiş gen transfer sistemlerinin entegrasyonu, yüksek meyve kalitesini uzun hasat sonrası raf ömrüyle birleştiren yeni çeşitlerin geliştirilmesine önemli ölçüde katkıda bulunabilir.

Anahtar Kelimeler: Genom Düzenleme; CRISPR/Cas9; Meyve Kalitesi; Raf Ömrü; Olgunlaşma.

ABSTRACT

Genome editing technologies stand out as a powerful approach offering targeted and rapid improvement compared to traditional breeding methods in fruit species characterized by long juvenile periods, high heterozygosity, polyploidy, and complex reproductive biology. Among current genome editing systems, CRISPR/Cas technologies are the most widely used tools in fruit species, and in recent years, base editing, prime editing, multiplex genome editing, and transgene-free editing approaches have further expanded the application potential of this technology. Current studies have shown that genome editing can be used to modify fundamental biological processes related to fruit ripening, shelf life, texture, nutritional content, color, aroma, and resistance to spoilage. In tomato, editing ripening-related genes such as *RIN* and *ALC* has been associated with altering the ripening process and extending shelf life, while multiplex targeting of *PSY1*, *MYB12*, and *SGR1* genes has shown that fruit color and nutritional composition can be improved simultaneously. In banana, the editing of the *MaACO1* gene, involved in ethylene biosynthesis, using CRISPR/Cas9 is a significant example of extending fruit shelf life.

Editing of the *IdnDH* gene, associated with tartaric acid biosynthesis in grapes, editing of PPO-related genes to reducing enzymatic browning in apples and other fruits, and the targeting of the *CsLOB1* gene to increase disease resistance in citrus fruits are among other studies that demonstrate genome editing can be used on different components of fruit quality. These applications show that postharvest life can be improved not only by delaying ripening but also by simultaneously preserving or improving sensory, nutritional, and commercial quality characteristics. However, the development of effective transformation and regeneration systems, pleiotropic effects, editing efficiency, transgene-free editing methods, regulatory compliance, and consumer acceptance remain significant limitations, particularly in perennial fruit species. In the future, the integration of precise genome editing, multiplex editing, genomic approaches, and advanced gene transfer systems could significantly contribute to the development of new varieties that combine high fruit quality with a long postharvest life.
Keywords: Genome Editing; CRISPR/Cas9; Fruit Quality; shelf life; Ripening.

INTRODUCTION

Fruit crops constitute an essential component of human nutrition and agricultural production because they provide dietary fiber, vitamins, minerals, antioxidants, and a wide range of health-promoting primary and secondary metabolites. They also represent economically important commodities in many regions of the world (Zhou et al., 2020; Martín-Valmaseda et al., 2023). However, fruits are highly perishable biological products that remain metabolically active after harvest. Respiration, transpiration, ripening, softening, senescence, water loss, physiological disorders, and pathogen development progressively reduce their commercial quality and storage potential. Consequently, postharvest loss and waste remain major constraints in horticultural supply chains. It has been estimated that approximately one-third of harvested produce may never be consumed, emphasizing the importance of developing strategies that preserve fruit quality for longer periods after harvest (Shipman et al., 2021; Kumari et al., 2022).

Fruit quality and postharvest life are closely interconnected traits. Consumer acceptance depends not only on external appearance and firmness but also on color, flavor, aroma, texture, nutritional value, and freedom from physiological deterioration and decay. At the same time, many of these attributes develop progressively during ripening, creating an inherent challenge for postharvest management. Fruit harvested close to optimum maturity generally exhibits superior sensory quality but is more susceptible to softening, mechanical injury, pathogen attack, and rapid senescence. Conversely, strategies that strongly suppress ripening to prolong storage may negatively affect flavor, texture, pigmentation, and nutritional quality (Shipman et al., 2021; Adaskaveg & Blanco-Ulate, 2023). This relationship is particularly important in climacteric fruits, in which ethylene plays a central role in coordinating ripening and senescence, although distinct hormonal and regulatory networks operate in non-climacteric fruits. Understanding and selectively modifying these regulatory pathways therefore offers an opportunity to extend postharvest life without sacrificing the characteristics that determine consumer preference (Adaskaveg & Blanco-Ulate, 2023; Ma et al., 2023).

Conventional fruit breeding has contributed substantially to improvements in yield, quality, disease resistance, and adaptability, but its efficiency is constrained by the biological characteristics of many fruit species. Long juvenile periods, high heterozygosity, self- or cross-incompatibility, large plant size, complex genetic backgrounds, and restricted availability of favorable alleles can make the development of improved cultivars slow and resource-intensive (Zhou et al., 2020; Martín-Valmaseda et al., 2023). These limitations are particularly pronounced in perennial fruit crops, where a single breeding cycle can extend over many years and the release of a new cultivar may require decades (Rane et al., 2025). Furthermore, many fruit-quality and postharvest characteristics are controlled by complex genetic and regulatory networks, making their simultaneous improvement through conventional crossing and selection difficult and frequently accompanied by linkage drag (Zhang & Zhu, 2024). The increasing demand for fruits combining extended shelf life with superior sensory and nutritional quality therefore requires breeding approaches capable of introducing desirable changes more rapidly and precisely.

Genome-editing technologies provide such an opportunity by enabling targeted modification of defined genomic regions.

Earlier platforms based on zinc-finger nucleases (ZFNs) and transcription activator-like effector nucleases (TALENs) demonstrated the feasibility of targeted genome modification, whereas the development of clustered regularly interspaced short palindromic repeat/CRISPR-associated protein (CRISPR/Cas) systems substantially increased the simplicity, efficiency, and versatility of genome editing in plants (Wan et al., 2021; Zhang & Zhu, 2024). CRISPR/Cas9 has subsequently been applied to a broad range of horticultural species, including tomato, strawberry, grapevine, apple, banana, citrus, papaya, and kiwifruit, with applications related to fruit quality, shelf life, disease resistance, and other agronomic traits (Sivasanakarreddy et al., 2026). More recently, CRISPR/Cas12a, base-editing and prime-editing systems have expanded the range and precision of possible genomic modifications, while avoiding or reducing some limitations associated with conventional double-strand-break-mediated editing (Ma et al., 2023; Sivasanakarreddy et al., 2026). Despite this potential, practical application in fruit crops continues to face challenges associated with transformation and regeneration efficiency, genotype dependence, polyploidy and heterozygosity, off-target modification, transgene elimination, regulatory frameworks, and public acceptance (Martín-Valmaseda et al., 2023; Sivasanakarreddy et al., 2026). Against this background, this proceeding paper discusses the potential of genome editing to improve fruit quality and optimize postharvest life, the major editing tools currently available, and their principal advantages, limitations, and future perspectives.

FRUIT QUALITY AND OPTIMIZED SHELF LIFE

Fruit quality is a multidimensional concept determined by the integration of visual, textural, sensory, nutritional, and physiological characteristics. Important attributes include color, gloss, firmness, juiciness, flavor, aroma, soluble sugars and organic acids, nutritional and bioactive compounds, and freedom from physiological disorders and decay. Shelf life is similarly a complex trait and reflects the ability of fruit to retain these desirable characteristics during storage, transportation, marketing, and consumption. Therefore, extending shelf life should not simply mean delaying deterioration for the longest possible period; rather, the objective should be to optimize shelf life while maintaining the sensory and nutritional quality expected by consumers (Shipman et al., 2021; Adaskaveg & Blanco-Ulate, 2023). This distinction is particularly important because many quality characteristics reach their optimum during ripening, whereas the same ripening process progressively increases susceptibility to softening, water loss, senescence, mechanical injury, and microbial decay.

Ripening is a highly coordinated developmental process involving hormonal signaling, transcriptional regulation, changes in pigmentation, cell-wall metabolism, sugar and organic acid composition, volatile formation, and accumulation or degradation of nutritionally important metabolites. Climacteric fruits such as tomato, banana, apple, peach, and kiwifruit undergo a marked increase in respiration and ethylene production during ripening, and ethylene acts as a major regulator of the transition toward senescence. Consequently, suppression or modulation of ethylene biosynthesis, perception, and downstream signaling can substantially delay ripening and increase storage potential (Shipman et al., 2021; Ma et al., 2023). Nevertheless, strong inhibition of ripening is not necessarily desirable because the same regulatory networks control the development of color, aroma, flavor, and texture. Thus, an excessively delayed-ripening phenotype may produce fruit with extended storage life but inferior eating quality. The central challenge is therefore to modify the rate and progression of ripening rather than completely suppressing it (Adaskaveg & Blanco-Ulate, 2023; Sivasanakarreddy et al., 2026).

Texture is among the most important determinants of both consumer acceptance and postharvest longevity. During ripening, progressive remodeling and degradation of cell-wall polysaccharides reduce tissue firmness and eventually increase susceptibility to mechanical damage and microbial invasion. Enzymes such as polygalacturonase (PG), pectin methylesterase (PME), pectate lyase (PL), β-galactosidase, and expansins participate in these processes. The fruit cuticle also contributes to texture and shelf life by limiting water loss, maintaining cellular turgor, and acting as a physical barrier against pathogens (Shipman et al., 2021; Kumari et al., 2022). Importantly, not all components of the softening pathway have equivalent effects. For example, alteration of PG activity does not consistently produce large improvements in firmness across species, whereas modification of PL-associated pathways has produced firmer fruit and extended shelf life in tomato and strawberry.

In tomato, CRISPR/Cas9-mediated disruption of *SlPL* significantly increased firmness and shelf life with relatively limited effects on color and other quality characteristics, illustrating the advantage of targeting specific downstream components of ripening rather than global ripening regulators (Adaskaveg & Blanco-Ulate, 2023).

Visual quality is another major determinant of marketability. Color is closely associated with ripening stage and is determined by the accumulation and degradation of pigments including chlorophylls, carotenoids, anthocyanins, and betalains. The cuticle additionally affects gloss and surface appearance. Manipulating pigmentation pathways may therefore enhance both visual attractiveness and nutritional value because many fruit pigments, particularly carotenoids and anthocyanins, also possess nutritional or antioxidant properties. However, these pathways are metabolically interconnected. Alteration of individual carotenoid or hormonal pathways may simultaneously affect ripening and texture, demonstrating why quality improvement should consider metabolic trade-offs rather than focus on a single phenotype (Adaskaveg & Blanco-Ulate, 2023). Nutritional quality can similarly be enhanced through regulation of pathways controlling carotenoids, anthocyanins, vitamin C, vitamin D precursors, γ-aminobutyric acid (GABA), sugars, and other metabolites. Recent studies summarized by Sivasanakarreddy et al. (2026) demonstrate that targeted modification of metabolic and regulatory genes can substantially alter carotenoid, GABA, sugar, amino acid, and antioxidant accumulation in horticultural crops.

Flavor must be considered simultaneously with visual quality and shelf life. Fruit flavor results from the interaction of sweetness, acidity, bitterness, texture, and a complex mixture of volatile organic compounds. Sugars and organic acids largely determine taste, whereas cultivar-specific combinations of volatile compounds contribute to aroma. Postharvest practices that prolong storage can negatively influence these characteristics; chilling, premature harvest, and artificial induction of ripening may alter volatile biosynthesis and sugar-to-acid balance (Adaskaveg & Blanco-Ulate, 2023). Therefore, breeding exclusively for firmness or delayed ripening risks producing fruit that tolerate transportation but fail to satisfy consumers. A more appropriate strategy is to retain or enhance flavor-associated metabolites while selectively slowing processes responsible for excessive softening and senescence.

Postharvest disease resistance represents another critical component of optimized shelf life. Ripening and senescence progressively weaken structural barriers and alter host physiology, increasing susceptibility to fungal and bacterial pathogens. *Botrytis*, *Penicillium*, *Alternaria*, *Colletotrichum*, *Monilinia*, and other postharvest pathogens can cause substantial losses during storage and distribution (Kumari et al., 2022). Structural properties such as cuticle integrity and cell-wall strength are therefore functionally connected with both firmness and disease resistance. Genetic modification of susceptibility or defense-associated pathways offers the possibility of reducing decay while also decreasing dependence on chemical postharvest treatments. Genome-editing studies have already demonstrated enhanced resistance to important pathogens in tomato, grapevine, apple, citrus, and other horticultural crops, although resistance responses remain dependent on pathogen variability, environmental conditions, and genetic background (Sivasanakarreddy et al., 2026).

Accordingly, the most useful objective for future fruit improvement is not simply maximum shelf life, but an optimized postharvest phenotype in which delayed senescence, adequate firmness, reduced water loss and decay, attractive appearance, desirable flavor, and high nutritional value are maintained simultaneously. Since these traits are governed by interconnected hormonal, transcriptional, metabolic, structural, and defense networks, modification of broad master regulators can produce undesirable pleiotropic effects. Greater precision may therefore be achieved by targeting function-specific regulators, downstream enzymes, regulatory regions, or selected alleles that fine-tune individual components of ripening and quality (Shipman et al., 2021; Adaskaveg & Blanco-Ulate, 2023). This biological framework provides the basis for applying modern genome-editing tools to develop fruits that combine commercial storage requirements with the quality characteristics demanded by consumers.

GENOME EDITING FOR FRUIT QUALITY AND OPTIMIZED SHELF LIFE

Genome-editing technologies have developed from protein-guided nucleases, particularly zinc-finger nucleases (ZFNs) and transcription activator-like effector nucleases (TALENs), toward highly programmable RNA-guided CRISPR systems. ZFNs and TALENs generate targeted double-strand DNA breaks (DSBs) through engineered DNA-binding domains coupled to the FokI nuclease.

The resulting breaks are repaired primarily through non-homologous end joining (NHEJ), which commonly produces small insertions or deletions, or through homology-directed repair (HDR), which can introduce defined sequence changes when a suitable repair template is available (Kumari et al., 2022; Ma et al., 2023). Although these earlier systems demonstrated the feasibility of targeted crop improvement, their requirement for complex protein engineering for each new genomic target limited their widespread application. TALEN-mediated modification of vacuolar invertase in potato, for example, reduced the accumulation of reducing sugars during cold storage and improved processing and food-quality characteristics, demonstrating the potential of targeted nucleases for postharvest improvement (Ahmar et al., 2020). However, among the uploaded literature, direct applications of ZFNs to fruit postharvest traits remain comparatively limited.

The development of CRISPR/Cas systems substantially increased the flexibility of genome editing because target specificity is determined principally by a programmable guide RNA rather than by redesigning a DNA-binding protein. CRISPR/Cas9, currently the most extensively applied genome-editing system in fruit crops, consists primarily of a Cas9 nuclease and a single-guide RNA (sgRNA) that directs cleavage to a complementary genomic sequence adjacent to a protospacer adjacent motif (PAM). Repair of the resulting DSB through NHEJ can generate gene knockouts, whereas HDR can be exploited for more precise sequence replacement (Zhou et al., 2020; Ma et al., 2023). Its relative simplicity, low cost, high efficiency, and multiplexing capacity have allowed CRISPR/Cas9 to become the principal genome-editing platform for modifying ripening, texture, nutritional composition, pigmentation, and disease-related traits in fruit crops.

One of the clearest applications of CRISPR/Cas9 to optimized shelf life has been the manipulation of fruit-ripening pathways. In tomato, editing of major ripening regulators including *RIN*, *NOR*, and *CNR* has generated altered ripening phenotypes and clarified the partially redundant regulatory networks controlling maturation. CRISPR/Cas9-mediated disruption of *RIN* delayed ripening, while editing of *lncRNA1459* also delayed tomato maturation. Targeted modification of the *ALC* locus through HDR has generated long-shelf-life tomato lines (Zhou et al., 2020; Kumari et al., 2022; Ma et al., 2023). More trait-specific editing may be particularly useful for avoiding undesirable effects associated with severe suppression of global ripening. For example, CRISPR/Cas9 editing of the tomato pectate lyase gene *SlPL* increased fruit firmness and shelf life while largely maintaining other quality characteristics, illustrating how downstream components of cell-wall metabolism can be manipulated to improve storage performance without completely inhibiting ripening (Kumari et al., 2022).

CRISPR/Cas9 has also provided opportunities to improve nutritional and sensory quality simultaneously with commercial postharvest characteristics. Editing *SlGAD2* and *SlGAD3* increased γ-aminobutyric acid (GABA) accumulation in tomato, while multiplex editing of several genes involved in GABA metabolism produced mutants with further enhanced GABA contents. Targeting *SlVPE5* and *INVINH1* increased soluble sugar accumulation, whereas editing a cis-regulatory upstream open reading frame associated with GDP-L-galactose phosphorylase increased ascorbate content. Carotenoid pathways have similarly been manipulated to modify fruit pigmentation and nutritional value (Ma et al., 2023). In banana, CRISPR/Cas9-mediated editing of *LCYε* produced up to a six-fold increase in β-carotene, while modification of carotenoid cleavage dioxygenase genes also increased β-carotene accumulation. Importantly for postharvest performance, knockout of *MaACO1*, which participates in ethylene biosynthesis, reduced ethylene production and extended banana shelf life without obvious vegetative growth defects (Ma et al., 2023). These examples illustrate that genome editing can address not only longevity but also the nutritional and sensory properties that determine the actual value of an extended shelf life.

CRISPR/Cas12a, formerly known as Cpf1, provides a complementary editing platform with characteristics that expand the accessible genomic target space. Unlike the commonly used SpCas9, which generally recognizes G-rich PAM sequences, Cas12a preferentially recognizes T-rich PAM regions. Cas12a also produces staggered rather than blunt DNA breaks and possesses intrinsic crRNA-processing activity, which facilitates the simultaneous expression of multiple guide RNAs. These characteristics make Cas12a particularly attractive for multiplex editing, regulatory-region modification, and targets located in AT-rich genomic regions (Bandyopadhyay et al., 2020). Its use in fruit crops is less extensive than Cas9, but Cas12a-mediated editing has already been demonstrated in citrus, and Cas9/Cas12a ribonucleoprotein-based approaches have been investigated in apple and grapevine cells

(Ahmar et al., 2020; Ma et al., 2023). Thus, Cas12a broadens rather than replaces the capabilities of Cas9.

More precise CRISPR-derived systems, particularly base editing and prime editing, offer additional possibilities for fine-tuning quality and shelf-life traits. Cytosine and adenine base editors combine catalytically modified Cas proteins with deaminases and can introduce specific nucleotide substitutions without conventional DSB formation. This capability is especially relevant when desirable fruit phenotypes depend on particular alleles rather than complete loss of gene function (Ma et al., 2023). Prime editing extends this precision further by combining a Cas9 nickase with reverse transcriptase and a prime-editing guide RNA (pegRNA). In principle, prime editing can generate all 12 possible base substitutions as well as defined small insertions and deletions without requiring a DSB or an exogenous donor DNA template (Tian et al., 2025). Prime editing has already been demonstrated in tomato, although its efficiency in plants, particularly in economically important crops, remains variable and frequently lower than that of conventional CRISPR/Cas9 editing. Therefore, the uploaded literature supports prime editing primarily as an emerging tool with strong potential for precise fruit-quality improvement, rather than as a technology already widely applied to postharvest traits.

Multiplex genome editing is particularly relevant to fruit quality because traits such as ripening, flavor, nutritional composition, pigmentation, and disease resistance are controlled by interacting gene networks rather than single genes. CRISPR-based multiplex systems allow several loci or multiple members of redundant gene families to be modified in a single transformation event. In tomato, simultaneous modification of *PSY1*, *MYB12*, and *SGR1*, which participate in carotenoid synthesis, flavonoid regulation, and chlorophyll degradation, respectively, has demonstrated the possibility of coordinating fruit color and nutritional composition (Lin et al., 2026). Multiplex approaches are also valuable in polyploid fruits, in which several alleles or homologous gene copies may need to be edited before a clear phenotype can be obtained.

Finally, transgene-free editing strategies are especially important for clonally propagated and perennial fruit crops because removal of integrated editing constructs through conventional segregation may require many years or may alter the genetic identity of an elite cultivar. DNA-free Cas–gRNA ribonucleoprotein delivery, transient expression, and selectable co-editing approaches can overcome part of this problem. Huang et al. (2023) demonstrated transgene-free editing in the T0 generation using a combined cytosine-base-editor/Cas12a co-editing strategy, achieving biallelic or homozygous transgene-free mutation frequencies ranging from 1.9% to 42.1% in tomato, tobacco, potato, and citrus. Transgene-free citrus lines carrying edits in the *LOB1* susceptibility promoter also exhibited canker resistance. Such strategies are particularly relevant to fruit breeding because they enable precise improvement of elite cultivars without the prolonged crossing required to eliminate transgenic components. Collectively, the transition from conventional site-directed nucleases to CRISPR/Cas9, Cas12a, base and prime editing, multiplex systems, and transgene-free delivery is shifting fruit improvement from broad modification of ripening toward increasingly precise manipulation of individual quality and postharvest traits.

ADVANTAGES, LIMITATIONS AND FUTURE PERSPECTIVES

Genome editing offers several important advantages for the improvement of fruit quality and postharvest performance. In contrast to conventional breeding, which depends on recombination and existing genetic variation, genome-editing systems enable targeted modification of specific genes or regulatory regions while largely preserving the genetic background of an elite cultivar. This is particularly valuable for perennial fruit crops, in which long juvenile periods, high heterozygosity, self- or cross-incompatibility, and vegetative propagation substantially prolong conventional breeding programs. CRISPR/Cas systems are also relatively flexible and programmable and can be used for gene knockout, targeted sequence modification, regulation of gene expression, and simultaneous editing of multiple loci (Zhou et al., 2020; Campa et al., 2024). Consequently, traits directly related to commercial fruit value, including delayed ripening, firmness, pigmentation, nutritional composition, flavor-associated metabolism, and disease resistance, can potentially be modified without the repeated crossing cycles required in traditional breeding.

Another major advantage is the possibility of simultaneously improving several components of complex fruit-quality phenotypes.

Many postharvest characteristics are controlled by interconnected metabolic and regulatory networks rather than by single genes. Multiplex genome editing can target several genes or alleles within these networks in a single editing strategy, which is particularly important in polyploid crops and in pathways exhibiting functional redundancy. Such approaches could ultimately permit coordinated optimization of firmness, color, nutritional composition, ripening behavior, and resistance to postharvest pathogens rather than improvement of one characteristic at the expense of another. Furthermore, genome editing may contribute to more sustainable production by reducing dependence on chemical inputs and decreasing losses occurring during storage and distribution (Zhang & Zhu, 2024; Lin et al., 2026).

Despite these advantages, the application of genome editing in fruit crops remains technically challenging. Transformation and plant regeneration are strongly genotype- and species-dependent, and many woody perennial species remain recalcitrant to tissue culture. Regeneration is particularly problematic after protoplast-mediated editing, limiting the practical use of DNA-free ribonucleoprotein (RNP) delivery in several fruit crops. In apple, for example, production of edited plants may require more than six months of tissue culture followed by several years of plant establishment, while a high frequency of chimerism has been reported in regenerated edited lines (Sivasanakarreddy et al., 2026). Polyploidy and high heterozygosity create additional difficulties because several alleles or homologous copies may need to be simultaneously modified to obtain a stable phenotype. These characteristics are common in commercially important fruit crops such as strawberry, banana, apple, and kiwifruit (Zhou et al., 2020).

Editing precision and phenotypic predictability also require careful consideration. Conventional CRISPR/Cas-mediated DSB repair through NHEJ can generate variable insertions and deletions, while unintended off-target modifications remain a potential concern. Improved guide-RNA design, high-fidelity Cas variants, and genome-wide sequence analysis can substantially reduce or identify these events (Zhou et al., 2020). More importantly for fruit quality, modification of master ripening regulators may produce pleiotropic effects because pathways controlling shelf life are closely connected with color, texture, flavor, aroma, and nutritional composition. Thus, extending shelf life by strongly suppressing ripening does not necessarily produce a commercially superior fruit. The future objective should be precise fine-tuning of ripening and senescence, allowing deterioration to be slowed while desirable sensory and nutritional characteristics are maintained (Sivasanakarreddy et al., 2026).

Newer editing platforms may help overcome some of these constraints. Base editing permits precise nucleotide substitutions without conventional DSB formation, whereas prime editing offers a broader “search-and-replace” strategy capable, in principle, of producing all 12 base substitutions as well as defined small insertions and deletions. These technologies could be particularly useful for reproducing favorable natural alleles or generating subtle modifications in regulatory regions rather than completely disrupting genes. Nevertheless, prime-editing efficiency in plants remains low and highly variable according to species, target locus, edit type, and pegRNA design, and considerable optimization is still required before routine application in fruit breeding (Tian et al., 2025). Multiplex editing, cis-regulatory editing, and CRISPR-based transcriptional or epigenetic regulation may further allow quantitative rather than all-or-nothing modification of fruit-quality pathways, providing greater control over complex phenotypes (Zhou et al., 2020; Campa et al., 2024).

The development of efficient transgene-free editing systems is another major future direction, particularly for clonally propagated and perennial fruits. Removal of integrated CRISPR constructs through segregation is straightforward in some annual crops but can be impractical in fruit trees because of long generation times, heterozygosity, and the need to preserve elite cultivar genomes. DNA-free RNP delivery, transient expression, viral delivery, graft-mobile editing, and co-editing strategies are therefore receiving increasing attention. Transgene-free, biallelic or homozygous edited plants have already been obtained in the T0 generation in tomato, potato, tobacco, and citrus using a selectable co-editing strategy, demonstrating the feasibility of bypassing additional generations for transgene removal (Huang et al., 2023). Emerging approaches aimed at overcoming regeneration barriers, including improved developmental regulators, virus-induced genome editing, de novo meristem induction, nanoparticles, and cell-penetrating peptides, could further broaden genome-editing accessibility in recalcitrant horticultural species (Sivasanakarreddy et al., 2026).

Finally, technological progress alone will not determine the commercial success of genome-edited fruits.

Regulatory frameworks differ among countries, and consumer acceptance continues to depend on perceptions of food safety, environmental effects, transparency, and the perceived benefits of the final product. Harmonized regulatory approaches, rigorous safety assessment, and clear communication regarding the distinction between transgenic and transgene-free genome-edited products will therefore be important for wider commercialization (Zhang & Zhu, 2024). From a consumer perspective, traits with direct and visible benefits, such as improved flavor and nutritional value, reduced browning and decay, and longer shelf life, may be particularly important for acceptance. Overall, the integration of precise base and prime editing, multiplex strategies, improved regeneration and delivery systems, and transgene-free approaches is expected to shift fruit breeding toward the development of cultivars in which postharvest longevity is optimized together with, rather than at the expense of, fruit quality.

CONCLUSION

Genome editing provides a practical way to improve fruit quality while extending postharvest life. Current tools can target ripening, firmness, color, nutritional value, and disease resistance more precisely than conventional breeding. However, the main challenge is not simply to delay ripening, but to maintain good flavor, texture, and nutritional quality during storage. Problems related to transformation, regeneration, polyploidy, off-target effects, and regulation still limit wider use in many fruit crops. Future progress in transgene-free editing, multiplex approaches, base editing, and prime editing may help overcome these limitations. Overall, genome editing has strong potential to support the development of high-quality fruits with better storage performance and reduced postharvest losses.

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MEYVE AROMA ANALİZİNDE HS-SPME: YÖNTEM SEÇİMİNİN UÇUCU BİLEŞİK PROFİLİ ÜZERİNDEKİ ETKİLERİ VE SINIRLILIKLARI

HS-SPME IN FRUIT AROMA ANALYSIS: EFFECTS AND LIMITATIONS OF METHOD SELECTION ON VOLATILE PROFILES

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ÖZET

Meyvelerin duyusal kalitesini ve tüketici kabulünü etkileyen en önemli kalite özelliklerinden biri aromadır. Meyve aroması, esterler, aldehitler, alkoller, ketonlar, terpenler ve diğer uçucu bileşiklerin karmaşık bir karışımıdır ve çeşit, olgunlaşma dönemi, hasat öncesi koşullar, hasat sonrası uygulamalar, depolama ve işleme yöntemlerinden büyük ölçüde etkilenmektedir. Uçucu bileşiklerin analizi için yaygın olarak kullanılan tepe boşluğu yaklaşımı, numuneyle doğrudan temas olmadan, numunenin üzerindeki gaz fazındaki uçucu bileşiklerin analizini içermektedir. Bu yöntemde, uçucu bileşiklerin polimer kaplı bir fiber üzerine adsorbe edildiği veya emildiği ve daha sonra bir gaz kromatografisi sisteminin enjeksiyon portunda termal olarak desorbe edildiği katı faz mikro ekstraksiyon (SPME) tekniği kullanılmaktadır. HS-SPME, çözücü gerektirmemesi, hızlı, ekonomik olması ve düşük numune hazırlığı gerektirmesi nedeniyle meyve aromasının analizinde yaygın olarak uygulanmaktadır. Bununla birlikte, elde edilen uçucu profil, kaplama tipi ve ekstraksiyon koşullarından büyük ölçüde etkilenmektedir. Karşılaştırmalı çalışmalar, PDMS/DVB, CW/DVB, DVB/CAR/PDMS ve CAR/PDMS fibrlerin, meyve matrisi ve hedef uçucu gruplara bağlı olarak ekstraksiyon verimliliğinde farklılık gösterdiğini ortaya koymuştur. Ekstraksiyon sıcaklığı, süresi, numune boyutu, iyonik kuvvet, desorpsiyon koşulları ve numune hazırlama yöntemleri de tanımlanan bileşiklerin sayısını ve dağılımını değiştirdiğini göstermektedir. Elma ve *Viburnum opulus*'ta farklı ekstraksiyon koşulları ve yöntemleri farklı uçucu profiller tespit ederken, çileklerde numune hazırlama ve sıcaklığın aldehitler ve esterler üzerinde özel bir etkisinin olduğunu göstermiştir. HS-SPME'nin önemli sınırlamalarından biri, farklı moleküler ağırlıklara ve uçuculuklara sahip bileşiklerin fiberle dengeye farklı sürelerde ulaşmasıdır; düşük moleküler ağırlıklı bileşiklerin elma uçucu bileşenlerinde hızla dengeye ulaştığı, yüksek moleküler ağırlıklı bileşikler için ise bu sürenin çok daha uzun olduğu bildirilmiştir. Ayrıca, HS-SPME, bölme katsayısına dayalı bir teknik olduğundan, tek bir dahili standarda dayalı yarı kantitatif değerlendirmeler her zaman gerçek miktarları doğru bir şekilde yansıtmayabilir. Özetlemek gerekirse, HS-SPME meyve aroması analizi için güçlü ve pratik bir yöntemdir. Ancak elde edilen uçucu bileşik profili; fiber türü, ekstraksiyon sıcaklığı ve süresi, numune hazırlama ve matris özelliklerinden önemli ölçüde etkilendiğinden, meyvelerin aroma profilinin doğru yorumlanabilmesi için yöntemin optimize edilmesi ve kullanılan analitik koşulların dikkatle değerlendirilmesi gerekmektedir.

Anahtar Kelimeler: HS-SPME; Meyve Aroması; Uçucu Bileşikler; SPME Fiberleri; Ekstraksiyon Koşulları.

ABSTRACT

One of the most important quality traits affecting fruit sensory quality and consumer acceptance is aroma. The aroma of fruit is a complicated mixture of esters, aldehydes, alcohols, ketones, terpenes and other volatile compounds and is greatly influenced by variety, ripening period, pre-harvest conditions, postharvest practices, storage and processing. The headspace approach, widely employed for the analysis of volatile compounds, involves the analysis of volatile compounds in the gas phase above the sample, without direct contact with the sample. In this method, the solid-phase microextraction (SPME) technique is utilized, where volatile compounds are adsorbed or absorbed onto a polymer-coated fiber, and subsequently thermally desorbed in the injection port of a gas chromatographic system.

HS-SPME is widely applied in the analysis of fruit aroma because it is solvent-free, fast, economical and requires low sample preparation. However, the resulting volatile profile is strongly influenced by fiber type and extraction conditions. Comparative studies have shown that PDMS/DVB, CW/DVB, DVB/CAR/PDMS, and CAR/PDMS fibers differ in extraction efficiency depending on the fruit matrix and target volatile groups. Extraction temperature, time, sample size, ionic strength, desorption conditions and sample preparation can also modify the number and distribution of compounds identified. In apples and *Viburnum opulus* different extraction conditions and modes detected different volatile profiles, while in strawberries sample preparation and temperature had a specific impact on aldehydes and esters. One of the important limitations of HS-SPME is that compounds with different molecular weights and volatilities reach equilibrium with the fiber in different times; it has been reported that low molecular weight compounds reach equilibrium quickly in apple volatiles, while this period is much longer for high molecular weight compounds. In addition, since HS-SPME is a technique based on the partition coefficient, semi-quantitative evaluations based on a single internal standard may not always accurately reflect the actual amounts. To summarize, HS-SPME is a strong and practical method for fruit aroma analysis, but the obtained volatile compound profile is strongly influenced by fiber type, extraction temperature and time, sample preparation and matrix properties. Therefore, method optimization and careful evaluation of the analytical conditions used are necessary for accurate interpretation of the aroma profile of the fruits.
Keywords: HS-SPME; Fruit Aroma; Volatile Compounds; SPME Fibers; Extraction Conditions.

INTRODUCTION

Aroma is one of the major sensory attributes determining fruit quality, consumer perception, and acceptance, and it also contributes to the characteristic identity of individual species and cultivars (Liang et al., 2022; Ong et al., 2008; Pereira et al., 2011). Fruit aroma is formed by a complex mixture of compounds, mainly including esters, alcohols, aldehydes, ketones, terpenes, lactones, and other volatile metabolites, whose composition varies with genotype, cultivar, maturity stage, environmental conditions, and pre- and postharvest practices (Ferreira et al., 2009; Liang et al., 2022; Pontes et al., 2009; Zarifikhosroshahi et al., 2020). However, the contribution of these compounds to aroma is not simply related to their abundance, since compounds occurring at relatively low concentrations may have an important sensory effect depending on their odor thresholds (Fan et al., 2010; Ferreira et al., 2009). For this reason, characterization of volatile profiles has become an important tool not only for describing fruit aroma, but also for distinguishing cultivars, evaluating ripening and postharvest changes, assessing quality, and identifying responses to factors such as mechanical damage (Mariano et al., 2022; Martínez et al., 2022; Ong et al., 2008).

The analysis of fruit aroma requires the effective isolation of volatile compounds from a highly complex and dynamic biological matrix. Conventional approaches, including solvent extraction, simultaneous distillation–extraction, purge-and-trap, and related techniques, have been widely used, but they may involve large amounts of solvent, time-consuming sample preparation, losses of highly volatile compounds, or the formation of analytical artifacts (Ceva-Antunes et al., 2006; Ferreira et al., 2009; Ibáñez et al., 1998; Pontes et al., 2009). Headspace solid-phase microextraction (HS-SPME) has therefore become one of the most widely applied alternatives because it combines sampling, extraction, and concentration with relatively simple sample handling and without the use of organic solvents (Augusto et al., 2000; Ceva-Antunes et al., 2006; Ibáñez et al., 1998). When coupled with gas chromatography–mass spectrometry (GC-MS), HS-SPME provides a sensitive and practical approach for screening complex fruit volatile profiles and has been successfully applied to fruits with markedly different aroma compositions, including strawberry, grape, apple, passion fruit, jackfruit, citrus, papaya, and other species (Fan et al., 2010; Ong et al., 2008; Pereira et al., 2011; Vandendriessche et al., 2013). Nevertheless, the simplicity of the technique should not imply that the profile obtained represents the complete volatile composition of the fruit.

HS-SPME is an equilibrium- and partition-based extraction technique in which analytes are distributed among the sample matrix, the headspace, and the fiber coating. Consequently, the amount of each compound reaching the fiber depends on its physicochemical properties and its affinity for both the headspace and the selected coating (Ferreira et al., 2009; Jelen & Wieczorek, 2023; Ong et al., 2008; Pontes et al., 2009).

Fiber selection is therefore a critical step, and the fiber giving the highest total extraction efficiency does not necessarily provide the most representative profile for every fruit or every chemical class. For example, CW/DVB showed the highest extraction efficiency for kiwi and papaya, whereas PDMS/DVB was more effective for lemon and plum, demonstrating that a single fiber cannot be considered universally optimal for fruit aroma analysis (Pereira et al., 2011). Similarly, Ferreira et al. (2009) detected 58 apple volatiles using DVB/CAR/PDMS compared with only 24 using PDMS, while Ceva-Antunes et al. (2006) identified 27 compounds in siriguela with DVB/CAR/PDMS but only 10 with PDMS. An important point is that a lower overall extraction response does not necessarily mean lower analytical value: in *Eugenia klotzschiana*, DVB/CAR/PDMS produced the smallest total extracted area but recovered several compounds that were not detected with the other tested coatings (Mariano et al., 2022). Differences are not restricted to fiber chemistry, since HS-SPME and immersion-SPME also produced different numbers and distributions of compounds in *Viburnum opulus*, and direct and indirect extraction approaches showed different performances in the analysis of mechanically damaged apples (Martínez et al., 2022; Zarifikhosroshahi et al., 2020).

Extraction temperature and time introduce another important source of variation. Increasing temperature generally promotes the transfer of compounds into the headspace, but excessive heating may reduce the recovery of some analytes or induce changes in the original volatile composition, while extraction time determines whether individual compounds approach equilibrium and whether competition for adsorption sites becomes important (Fan et al., 2010; Mariano et al., 2022). These effects are clearly illustrated in strawberry, where increasing the measurement temperature increased mainly ester abundance and sample blending altered the levels of several compounds, showing that even sample preparation can modify the profile before chromatographic analysis (Vandendriessche et al., 2013). Extraction time can also change the apparent relative composition: Matich et al. (1996) showed that low-molecular-weight apple volatiles reached equilibrium rapidly, whereas higher-molecular-weight compounds did not equilibrate even after prolonged sampling, and the relative contribution of α-farnesene increased substantially as sampling time was extended. Comparable effects have been associated with fiber saturation and desorption during prolonged extraction in jackfruit (Ong et al., 2008). Therefore, peak-area percentages obtained by HS-SPME should be interpreted cautiously because differences in partition behavior, fiber selectivity, matrix effects, and detector response mean that relative chromatographic areas do not necessarily correspond to the actual proportions of compounds in the fruit (Ceva-Antunes et al., 2006; Ibáñez et al., 1998; Jelen & Wieczorek, 2023). This issue becomes particularly important when quantitative conclusions are drawn, since reliable HS-SPME quantification requires appropriate calibration for individual analytes rather than assuming that different compounds respond in the same manner relative to a single internal standard (Jelen & Wieczorek, 2023). Accordingly, HS-SPME should be considered a highly useful but inherently selective method for fruit aroma analysis. The volatile profile obtained represents the interaction between the biological sample and the analytical conditions selected rather than an absolute description of the entire fruit volatilome. This paper therefore discusses the principles and applications of HS-SPME in fruit aroma analysis, with particular emphasis on how fiber type, extraction conditions, sample preparation, and matrix effects influence the detected volatile profile, and evaluates the main limitations that should be considered when interpreting and comparing results among studies.

PRINCIPLES AND APPLICATION OF HS-SPME IN FRUIT AROMA ANALYSIS

Headspace solid-phase microextraction (HS-SPME) has become one of the most commonly used sample preparation techniques for the analysis of volatile compounds in fruits and other food matrices. Solid-phase microextraction was introduced as a solvent-free alternative to conventional extraction procedures and combines extraction and preconcentration in a relatively simple analytical step (Augusto et al., 2000; Ibáñez et al., 1998). In its basic configuration, an SPME device consists of a fused-silica fiber coated with a stationary phase that interacts selectively with volatile and semi-volatile compounds. In headspace analysis, the fiber is not placed directly in contact with the fruit matrix but is exposed to the gas phase above the sample, which reduces direct interference from non-volatile matrix components and facilitates the transfer of volatile compounds to the fiber (Jelen & Wieczorek, 2023).

The principle of HS-SPME is based on the distribution of volatile compounds among the fruit matrix, the headspace, and the fiber coating.

Following placement of the fruit sample or homogenate in a sealed vial, volatile compounds migrate from the matrix into the headspace and are subsequently absorbed or adsorbed by the fiber coating until a distribution equilibrium, or a defined extraction condition, is approached (Ong et al., 2008). The extraction process therefore depends on the physicochemical characteristics of both the volatile compounds and the coating material. Molecular weight, polarity, boiling point, vapor pressure, and functional groups influence the affinity of individual compounds for different fiber coatings (Pontes et al., 2009). Commercial fibers consequently differ considerably in selectivity. Common coatings used in fruit aroma studies include polydimethylsiloxane (PDMS), polyacrylate (PA), carboxen/polydimethylsiloxane (CAR/PDMS), polydimethylsiloxane/divinylbenzene (PDMS/DVB), and divinylbenzene/carboxen/polydimethylsiloxane (DVB/CAR/PDMS) (Ferreira et al., 2009; Mariano et al., 2022). Mixed coatings are particularly useful in complex fruit matrices because they provide interactions with compounds covering a wider range of polarity and volatility.

After extraction, the fiber is withdrawn into the protective needle and transferred directly to the injection port of the gas chromatograph. The retained volatile compounds are thermally desorbed and introduced into the chromatographic column, where they are separated before detection, most commonly by mass spectrometry (Ceva-Antunes et al., 2006; Ferreira et al., 2009). Compound identification generally combines mass spectral library matching with chromatographic retention information, particularly retention indices determined using a homologous series of alkanes (Ceva-Antunes et al., 2006). This combination has made HS-SPME coupled with GC-MS particularly suitable for qualitative and semi-quantitative characterization of complex fruit aromas. Different GC-MS configurations can also be used depending on analytical objectives. For example, quadrupole mass spectrometry has been extensively applied in apple and passion fruit profiling, whereas GC coupled with time-of-flight mass spectrometry has provided rapid acquisition and separation of jackfruit volatiles (Ong et al., 2008; Pontes et al., 2009). Fast GC-MS approaches have similarly been developed for strawberry aroma analysis to increase sample throughput while maintaining adequate chromatographic resolution (Vandendriessche et al., 2013).

One of the principal applications of HS-SPME is the establishment of characteristic volatile fingerprints of fruits. Early applications demonstrated that the technique could recover representative aroma compounds from strawberry, raspberry, blackberry, banana, mango, and several tropical fruits without extensive solvent-based preparation (Augusto et al., 2000; Ibáñez et al., 1998). Subsequent studies extended the approach to many horticultural species and showed that volatile profiles could contain esters, alcohols, aldehydes, ketones, acids, terpenes, lactones, and other compound classes in markedly different proportions. For example, HS-SPME-based analysis identified approximately 100 volatile compounds among the pulp, peel, and whole-fruit samples of different apples, while application to passion fruit species allowed the tentative identification of 71 compounds (Ferreira et al., 2009; Pontes et al., 2009). In jackfruit, SPME-GC-TOFMS identified 37 volatile compounds and differentiated five cultivars according to their flavor composition (Ong et al., 2008). Likewise, studies involving lemon, kiwi, papaya, and plum demonstrated that HS-SPME profiles can provide characteristic chemical fingerprints for individual fruit species (Pereira et al., 2011). Such observations are consistent with the broader diversity of fruit aroma, which is strongly associated with species, cultivar, ripening stage, fruit tissue, environmental conditions, and postharvest handling (Liang et al., 2022).

HS-SPME is therefore useful not only for identifying volatile compounds but also for examining biological variation among fruit samples. Volatile profiles have been applied to distinguish cultivars, species, production locations, and fruit tissues, frequently in combination with multivariate statistical approaches such as principal component analysis. Ferreira et al. (2009), for instance, used volatile composition to discriminate apples originating from different geographic locations, whereas Ong et al. (2008) successfully separated jackfruit cultivars using principal component analysis. In grapes, HS-SPME-GC-MS has been combined with odor-active compound analysis to characterize varietal aroma and quantify compounds with potentially important sensory contributions (Fan et al., 2010). The technique has also been employed to investigate changes occurring during ripening, storage, processing, and other postharvest conditions, making volatile profiling useful as an additional indicator of fruit quality.

More specific applications illustrate the sensitivity of volatile analysis to physiological and physical changes in fruit.

In strawberry, HS-SPME-GC-MS has been used to investigate differences among fruit tissues and changes associated with sample handling and extraction conditions (Vandendriessche et al., 2013). In apple, volatile fingerprints obtained with different SPME approaches have been evaluated as potential markers of mechanical damage, with particular changes detected among ester compounds in damaged fruit (Martínez et al., 2022). HS-SPME and immersion-SPME have also been compared in *Viburnum opulus*, where the number and composition of detected volatiles varied according to extraction mode and temperature, demonstrating the usefulness of SPME-based approaches for characterizing fruits originating from different ecological conditions (Zarifikhosroshahi et al., 2020). In *Eugenia klotzschiana*, optimization of HS-SPME enabled characterization of a previously poorly described volatile profile dominated by sesquiterpenes and monoterpenes (Mariano et al., 2022).

Despite its broad application, HS-SPME should be understood primarily as a partition-based sampling technique rather than an exhaustive extraction procedure. The amount of a compound recovered by the fiber is governed by its distribution between the sample and headspace and between the headspace and fiber coating (Jelen & Wieczorek, 2023). Earlier work with apple volatiles also demonstrated that compounds with different molecular weights and physicochemical properties may show markedly different equilibration behavior during headspace sampling (Matich et al., 1996). Thus, successful use of HS-SPME in fruit aroma analysis requires the analytical conditions to be selected according to the fruit matrix and the objective of the study. Fiber coating, extraction temperature and duration, sample preparation, ionic strength, and other experimental parameters consequently become critical determinants of the volatile profile obtained, and these methodological factors are considered in the following section.

METHODOLOGICAL FACTORS AFFECTING VOLATILE PROFILES

The volatile profile obtained by HS-SPME is strongly dependent on the conditions selected during sampling and extraction. Because HS-SPME is based on partitioning among the sample matrix, headspace, and fiber coating, even relatively small changes in experimental conditions may affect the amount and proportion of compounds transferred to the fiber (Ferreira et al., 2009; Jelen & Wieczorek, 2023). Therefore, optimization should not be considered only as a procedure for maximizing total peak area. The selected conditions should provide sufficient extraction efficiency while maintaining a volatile profile that is representative of the fruit matrix. Fiber coating, extraction temperature and time, sample preparation, sample amount, ionic strength, agitation, and desorption conditions are among the main variables determining the resulting chromatographic profile (Ferreira et al., 2009).

Sample preparation is particularly important because fruits remain biologically active after harvest and tissue disruption may rapidly initiate enzymatic reactions. Homogenization improves sample uniformity and facilitates volatile release, but cutting, crushing, or blending can simultaneously modify the composition being measured. In strawberry, blending substantially altered the volatile pattern and increased several compounds, including hexanal, 2-hexenal, hexanoic acid, and 2,3-butanedione, the latter being detected only after tissue disruption (Vandendriessche et al., 2013). This response was associated mainly with activation of pathways involved in the formation of C6 compounds following tissue damage. Consequently, the volatile profile of homogenized fruit cannot always be assumed to be identical to that released by intact fruit. Enzyme inhibition after homogenization has therefore been used in several studies to stabilize the samples. Ferreira et al. (2009), for example, added $CaCl_2$ during apple homogenization, while grape samples have been crushed under nitrogen to minimize changes during preparation (Fan et al., 2010). Tissue selection is another consideration. In strawberry, the outer tissues contained higher levels of several esters than the inner vascular and pith tissues, indicating that sampling only one portion of the fruit can introduce additional variation into aroma comparisons (Vandendriessche et al., 2013).

Among the extraction parameters, fiber coating has one of the most direct effects on the number, identity, and relative abundance of detected compounds. Commercial coatings differ in polarity, sorption mechanism, and affinity for compounds with different molecular weights, boiling points, and vapor pressures. Accordingly, there is no single coating capable of extracting all fruit volatiles with equal efficiency (Ceva-Antunes et al., 2006; Pontes et al., 2009). PDMS is generally more suitable for nonpolar compounds, whereas PA shows greater affinity for relatively polar semivolatiles.

Mixed coatings such as PDMS/DVB, CAR/PDMS, and DVB/CAR/PDMS broaden the range of compounds that can be recovered and are consequently widely used for fruit aroma profiling (Pontes et al., 2009). However, the optimal coating remains matrix-dependent. DVB/CAR/PDMS produced the most complete profile among the tested fibers for apple, strawberry, jackfruit, and siriguela (Ceva-Antunes et al., 2006; Ferreira et al., 2009; Ong et al., 2008; Vandendriessche et al., 2013), whereas PDMS/DVB performed best for passion fruit and for *Eugenia klotzschiana* (Mariano et al., 2022; Pontes et al., 2009). Pereira et al. (2011) further demonstrated that CW/DVB provided the highest extraction efficiency for kiwi and papaya, while PDMS/DVB was more suitable for lemon and plum. These differences clearly show that selection of a fiber based solely on its frequent use in previous studies may not provide the most representative profile for another fruit matrix.

Extraction temperature influences both the release of volatiles from the fruit matrix and their distribution between the sample, headspace, and fiber. Increasing temperature generally increases vapor pressure and accelerates mass transfer, thereby improving the movement of many volatile compounds into the headspace (Ferreira et al., 2009; Vandendriessche et al., 2013). However, the relationship is not linear for all compounds. Fan et al. (2010) observed increased extraction of grape volatiles as temperature increased to 60 °C, whereas extraction efficiency for lower-molecular-weight compounds decreased markedly at 70 °C. Similarly, Ceva-Antunes et al. (2006) emphasized that higher temperatures may facilitate adsorption-desorption processes but can also increase the risk of artifact formation or degradation of aroma compounds. The effect may also vary according to the selected fiber. In *E. klotzschiana*, temperature significantly influenced extraction with PDMS/DVB and DVB/CAR/PDMS, whereas no significant temperature effect was observed with PA under the investigated conditions (Mariano et al., 2022). Thus, extraction temperature should be optimized together with fiber type rather than treated as an independent parameter. In studies intended to approximate aroma perceived during consumption, excessively high temperatures may also be inappropriate. Ibáñez et al. (1998), for example, selected 30 °C for analysis of real fruit samples despite obtaining higher recoveries at 60 °C with a standard mixture, because the lower temperature was considered closer to normal consumption conditions.

Extraction and incubation times have similar importance because HS-SPME does not provide instantaneous equilibrium. Analytes with different physicochemical characteristics may require very different periods to transfer from the matrix to the headspace and subsequently to the fiber. In apple, increasing DVB/CAR/PDMS exposure from 15 to 75 min increased extraction efficiency, although Ferreira et al. (2009) selected 30 min because the number and overall profile of compounds were essentially similar to those obtained after 75 min. For strawberry, 30 min at 40 °C provided the highest overall peak abundance among the evaluated conditions (Vandendriessche et al., 2013), whereas a 40 min extraction was selected for passion fruit (Pontes et al., 2009). In contrast, approximately 20 min was sufficient for optimized extraction of *E. klotzschiana* volatiles with PDMS/DVB (Mariano et al., 2022). Extending extraction time therefore does not automatically improve the analytical result. Prolonged exposure may lead to competition among compounds for active sites on the fiber, while very short sampling periods may fail to approach equilibrium and can underestimate compounds with slower transfer rates (Fan et al., 2010). These effects are particularly important when relative peak areas are compared among compounds or among studies performed using different extraction times.

The relationship between sample amount and headspace volume must also be controlled. Increasing the quantity of fruit placed in a vial increases the amount of analyte available, but it simultaneously reduces headspace volume and modifies phase ratios. Thus, a larger sample does not necessarily produce greater or more reproducible extraction. Ferreira et al. (2009) obtained a higher total extraction response from 0.5 g of apple than from 1.0 g in a 4-mL vial, while 0.75 g was ultimately selected because it provided good extraction with lower variability. A similar interaction between sample quantity, time, and temperature was observed for *E. klotzschiana*, where increasing pulp quantity did not consistently increase extraction yield (Mariano et al., 2022). Sample amount and vial volume should therefore be standardized within an experiment and clearly reported when results are compared across studies.

Modification of ionic strength is another commonly used approach to enhance HS-SPME extraction. Addition of NaCl reduces the solubility of many volatile compounds in the aqueous phase and promotes their transfer into the headspace through the salting-out effect (Fan et al., 2010; Ferreira et al., 2009).

In strawberry, NaCl addition was also used to suppress enzymatic activity after blending and contributed to stabilization of the volatile profile during frozen storage (Vandendriessche et al., 2013). However, the effect is compound-dependent. In the same study, NaCl addition caused relatively limited changes in the overall strawberry aroma pattern, while hexanoic acid showed a clearer increase. Therefore, salt addition should not be assumed to enhance all volatile classes uniformly. The amount and concentration of salt need to remain consistent, particularly when relative abundances are used for cultivar, treatment, or storage comparisons.

Agitation can further improve mass transfer by reducing the stagnant boundary layer between the sample and headspace. Constant stirring has therefore been incorporated into many fruit HS-SPME procedures. For example, Ferreira et al. (2009) used magnetic stirring at 800 rpm for apple analysis, while Pontes et al. (2009) applied 750 rpm during passion fruit extraction. The latter authors noted that agitation facilitates transport from the aqueous sample by disrupting the static layer resistant to mass transfer. Nevertheless, agitation should also be standardized because changes in mass transfer kinetics may alter the rate at which different compounds reach the headspace and fiber.

Finally, fiber conditioning and desorption conditions influence analytical reproducibility and the risk of carryover. After extraction, compounds retained on the fiber are thermally desorbed in the GC injector, and insufficient desorption can leave residual analytes that interfere with subsequent samples. Ferreira et al. (2009) compared desorption periods of 3, 6, and 9 min and selected 6 min to obtain adequate desorption while minimizing carryover. Similar 6-min desorption periods were used in passion fruit and several other fruit studies (Pereira et al., 2011; Pontes et al., 2009), whereas Fan et al. (2010) used 5 min for grape volatiles. Blank injections and appropriate fiber conditioning are therefore important, particularly when samples with markedly different volatile concentrations are analyzed sequentially.

Taken together, these studies demonstrate that the volatile profile produced by HS-SPME is the outcome of several interacting methodological factors rather than a direct and method-independent representation of fruit aroma. Optimization should therefore be performed for the specific fruit matrix and analytical objective. More importantly, fiber type, sample preparation, extraction temperature and time, sample-to-headspace ratio, salt addition, agitation, and desorption conditions should be reported in sufficient detail. Without this information, differences attributed to cultivar, maturity, storage, or treatment may partly reflect analytical conditions rather than true biological variation.

EFFECTS AND LIMITATIONS OF METHOD SELECTION ON VOLATILE PROFILING

Although HS-SPME is highly effective for rapid characterization of fruit volatiles, the resulting chromatographic profile should not be considered an absolute representation of all volatile compounds present in the sample. The method is selective by nature, and the compounds detected, their relative peak areas, and even the apparent dominant chemical classes depend partly on the extraction conditions applied. Consequently, two studies analyzing the same or similar fruit material may obtain different volatile profiles when different fibers, extraction temperatures, sampling times, sample preparation procedures, or headspace conditions are used (Ferreira et al., 2009; Jelen & Wieczorek, 2023). This method-dependent behavior represents one of the most important issues when HS-SPME data are used to compare cultivars, treatments, maturity stages, or storage conditions.

Fiber selectivity provides the clearest example of this limitation. Different coatings have different affinities for volatile compounds according to polarity, molecular size, volatility, and other physicochemical characteristics. Therefore, a compound that is absent from a chromatogram may not necessarily be absent from the fruit, but may simply have been poorly extracted under the selected conditions. Ferreira et al. (2009) identified 58 compounds in apple pulp with DVB/CAR/PDMS, compared with only 24 using PDMS under the same extraction conditions. Similarly, Ceva-Antunes et al. (2006) identified 27 compounds in siriguela using DVB/CAR/PDMS but only 10 with PDMS. In passion fruit, the number of compounds detected varied from 28 with PA to 51 with PDMS/DVB (Pontes et al., 2009). These differences are not limited to the total number of compounds. The relative representation of individual chemical classes can also change according to coating selectivity. Thus, comparisons among studies based on a single fiber should consider that the reported “volatile profile” actually represents the fraction of the volatilome favored by that particular extraction system.

A fiber producing the largest total peak area is also not necessarily the fiber providing the most chemically comprehensive information.

Mariano et al. (2022) found that DVB/CAR/PDMS produced the smallest total extracted volatile area from *Eugenia klotzschiana*, yet five compounds were recovered exclusively with this coating. Likewise, the most efficient fiber varied according to fruit matrix in the study of Pereira et al. (2011): CW/DVB performed better for kiwi and papaya, whereas PDMS/DVB gave higher extraction efficiency for lemon and plum. Earlier screening of Brazilian fruit aromas also showed pronounced differences among coatings, with CAR/PDMS providing the highest overall extraction response in the evaluated matrices (Augusto et al., 2000). Therefore, labeling one commercial fiber as universally suitable for "fruit aroma" is difficult to justify. Mixed coatings may provide broader coverage, but no coating can be expected to extract all compounds with equivalent efficiency.

Another important limitation results from the nonequilibrium or compound-specific equilibrium behavior of HS-SPME. Volatile compounds differ substantially in their rates of transfer from the fruit matrix to the headspace and from the headspace to the fiber. Matich et al. (1996) demonstrated this particularly clearly in apple. Lower-molecular-weight volatiles approached equilibrium within approximately 5–10 min, whereas several higher-molecular-weight compounds had not reached equilibrium even after 90 min. More importantly, changing sampling duration altered the apparent composition of the chromatogram: the contribution of α-farnesene increased from approximately 65% of total integrated peak area after 5 min to 82% after 90 min. Thus, extraction time can change not only signal intensity but also the apparent relative importance of individual compounds. Fan et al. (2010) similarly noted that prolonged exposure can result in competition for fiber sites, whereas insufficient extraction time may fail to establish adequate equilibrium among the sample, headspace, and fiber. Such behavior makes direct comparison of relative abundances obtained using different sampling times particularly problematic.

Matrix effects add another level of complexity. Fruit is not a simple aqueous solution but a heterogeneous biological material containing sugars, acids, lipids, cell-wall components, water, and numerous other compounds that influence volatile partitioning. The efficiency of HS-SPME is controlled by both sample-to-headspace and headspace-to-fiber partitioning, and compounds with different Henry's constants, polarity, and hydrophobicity therefore behave differently even when present at similar concentrations (Jelen & Wieczorek, 2023). Matich et al. (1996) also demonstrated that high-molecular-weight apple volatiles could be affected by slow transfer from the fruit surface, depletion from the headspace during sampling, and adsorption onto glass surfaces. These effects mean that the amount reaching the detector may reflect several physical processes in addition to the actual concentration of the compound in the fruit.

The extraction mode itself can further change the resulting profile. In *Viburnum opulus*, Zarifikhosroshahi et al. (2020) detected 23 and 35 compounds by HS-SPME at 28 and 40 °C, respectively, whereas immersion-SPME yielded 44 and 38 compounds under the corresponding temperatures. Similarly, comparison of different sampling approaches in mechanically damaged apples showed that extraction configuration and fiber type affected the ability to recover volatile markers associated with fruit damage (Martínez et al., 2022). Therefore, differences among profiles generated by HS-SPME, direct immersion SPME, or other extraction techniques should not automatically be attributed to biological variation.

Sample manipulation can also create a profile that differs from that of the intact fruit. Vandendriessche et al. (2013) showed that blending strawberries increased several volatile compounds, particularly hexanal, 2-hexenal, and hexanoic acid, while 2,3-butanedione was detected only after blending. Increasing the analysis temperature to 40 °C mainly increased ester abundance compared with measurements of intact fruit at room temperature. These findings illustrate an important interpretative problem: a change detected analytically may originate from the biological treatment being studied, but it may also arise during sample preparation or extraction. The risk is especially relevant for compounds produced through rapidly activated enzymatic pathways following tissue disruption. At the same time, overly high extraction temperatures may promote degradation or artifact formation, which further separates the measured chromatographic profile from the original aroma emitted by the intact fruit (Ceva-Antunes et al., 2006; Liang et al., 2022).

A further limitation concerns the interpretation of relative peak areas as concentrations. Relative chromatographic area is useful for fingerprinting and for comparing samples analyzed under identical conditions, but it does not necessarily represent the true relative concentration of individual volatile

compounds. Ceva-Antunes et al. (2006) explicitly treated relative peak areas as qualitative information because detector response and extraction efficiency differ among compounds. This distinction becomes even more important in HS-SPME because each compound has its own partition behavior. Jelen and Wieczorek (2023) demonstrated that estimating the concentrations of chemically different volatiles by simply comparing their peak areas with a single internal standard can produce strongly erroneous values. In their model experiment, the results obtained using such an approach differed dramatically from those obtained using external calibration. Therefore, expressions such as "content" or "concentration" should be avoided when data are derived only from normalized peak areas without appropriate calibration.

True quantitative HS-SPME requires a more rigorous approach. Calibration should account for individual analyte behavior, and ideally the calibration matrix should approximate the real sample matrix. Fan et al. (2010), for example, constructed calibration curves for individual grape aroma compounds and evaluated detection limits and recoveries before quantitative application. Such procedures are considerably more demanding when dozens of compounds are involved, which explains why HS-SPME is more commonly employed for qualitative or semi-quantitative profiling than for comprehensive absolute quantification (Jelen & Wieczorek, 2023). This distinction is particularly important when odor activity values are calculated because an inaccurate concentration estimate may lead directly to an incorrect conclusion regarding the sensory importance of a compound.

Compound identification is another source of uncertainty. GC-MS library matching is widely used for tentative identification, but mass spectral similarity alone may be insufficient for compounds with similar fragmentation patterns. Retention indices and authentic standards increase confidence in identification and should be incorporated whenever possible. Ceva-Antunes et al. (2006) observed differences in experimental retention indices when conventional alkane injection was used and therefore adapted the procedure by subjecting the alkane standards to SPME under conditions similar to those used for fruit samples. This example demonstrates that even seemingly secondary methodological choices may influence compound identification and consequently the final volatile profile reported.

These limitations do not reduce the value of HS-SPME as a fruit aroma analysis technique. Rather, they define the conditions under which the results should be interpreted. Its speed, solvent-free operation, relatively simple handling, and suitability for automation remain major advantages, although limited extraction capacity, fiber selectivity, carryover, potential fiber damage, and reduced sensitivity for some compounds in complex matrices have also been recognized (Liang et al., 2022). Moreover, methodological modifications can be successfully introduced when they are properly validated. Vandendriessche et al. (2013), for instance, reduced strawberry GC-MS analysis time substantially using a fast GC-MS approach and obtained a strong relationship with conventional GC-MS results without loss of the monitored aroma compounds.

Overall, HS-SPME volatile profiles are best interpreted as method-conditioned analytical fingerprints rather than exhaustive descriptions of fruit volatile composition. Comparisons are most reliable when samples are prepared and analyzed under identical and well-controlled conditions. Comparisons among independent studies require greater caution, particularly when fiber coating, extraction time and temperature, sample preparation, sample-to-headspace ratio, or data normalization procedures differ. Detailed reporting and appropriate validation of these variables are therefore essential to distinguish genuine biological differences from changes introduced by analytical methodology.

CONCLUSIONS AND FUTURE PERSPECTIVES

HS-SPME is a rapid, sensitive, and practical technique for characterizing fruit volatile profiles, but the results obtained are strongly influenced by methodological choices. Fiber coating, sample preparation, extraction temperature and time, matrix composition, and other analytical conditions can alter both the number of detected compounds and their apparent relative abundances. Therefore, HS-SPME profiles should be interpreted as method-dependent analytical fingerprints rather than complete representations of the fruit volatilome.

Reliable comparison among samples and studies requires careful optimization, strict standardization of experimental conditions, and detailed reporting of the analytical procedure. Particular caution is also needed when relative peak areas are interpreted as concentrations or used to identify compounds as major contributors to aroma without appropriate calibration.

Future studies should focus on improved method standardization, better quantitative strategies, and validation across different fruit matrices. The combined use of complementary fiber coatings, automated sampling, advanced GC-MS systems, and chemometric approaches may further improve the coverage and reproducibility of volatile profiling. Such developments will strengthen the use of HS-SPME in fruit quality evaluation, breeding, postharvest research, and aroma-related studies while allowing more reliable comparisons among experiments.

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PANGENOMICS AND GRAPH GENOMES: EMERGING TOOLS FOR HORTICULTURAL CROP IMPROVEMENT

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ÖZET
Uzun okuma dizileme, haplotip çözünürlüklü genom montajları, pangenomik ve graf genom teknolojilerindeki gelişmeler, bahçe bitkilerinde genomik araştırmaları ve ıslah çalışmalarını önemli ölçüde dönüştürmektedir. Tek bir doğrusal referans genom, tür içindeki geniş genetik ve yapısal çeşitliliği tam olarak temsil edemezken, pangenomlar birden fazla genotipe ait çekirdek, değişken ve genotipe özgü bölgelerin birlikte incelenmesine olanak sağlamaktadır. Graf genomlar ise alternatif alleller ve yapısal varyasyonları ortak bir çerçevede temsil ederek referans yanlılığını azaltmakta ve varyant belirleme ile genotipleme doğruluğunu artırmaktadır. Elma, turunçgiller, kivi, ceviz, kayısı, fındık ve çilekte yapılan çalışmalar, bu yaklaşımların meyve kalitesi, olgunlaşma, çevresel adaptasyon, hastalık dayanıklılığı ve domestikasyonla ilişkili genetik varyasyonların ortaya çıkarılmasındaki önemini göstermektedir. Buna karşılık Antepfıstığı, badem ve alıç gibi bazı ekonomik türlerde kapsamlı pangenomik kaynaklar hâlen sınırlıdır. Bu derlemede, bahçe bitkilerinde pangenomik ve graf genom çalışmalarındaki güncel gelişmeler, özellik keşfi ve ıslahtaki uygulamaları ile bu teknolojilerin fenotipleme, omik yaklaşımlar, genomik seleksiyon, yapay zekâ ve genom düzenleme ile entegrasyonuna yönelik gelecek perspektifleri ele alınmıştır.
Anahtar Kelimeler: Pangenom; Graf Genom; Yapısal Varyasyon; Bahçe Bitkileri; GWAS; Genomik Seleksiyon; Hassas Islah.

ABSTRACT
Advances in long-read sequencing, haplotype-resolution genome assemblies, pangenomics, and graph genome technologies are significantly transforming genomic research and breeding into horticultural plants. While a single linear reference genome cannot fully represent the wide genetic and structural diversity within a species, pangenomes allow for the simultaneous examination of core, variant, and genotype-specific regions belonging to multiple genotypes. Graph genomes, on the other hand, reduce reference bias by representing alternative alleles and structural variations within a common framework, and improve the accuracy of variant identification and genotyping. Studies in tomato, cucumber, apples, citrus fruits, kiwis, walnuts, apricots, hazelnuts, and strawberries demonstrate the importance of these approaches in revealing genetic variations associated with fruit quality, ripening, environmental adaptation, disease resistance, and domestication. In contrast, comprehensive pangenomic resources are still limited for some economically important species such as pistachios, almonds, and hawthorns. The review focuses on the recent advances in pangenomics and graphene genome studies in horticultural plants, their application in trait discovery and breeding, and the future perspectives of combining these technologies with phenotyping, omics approaches, genomic selection, artificial intelligence, and genome editing.
Keywords: Pangenome, Graphene Genome, Structural Variation, Horticultural Plants, GWAS, Genomic Selection, Precision Breeding.

1. Introduction

The rapid development of next-generation sequencing technologies has profoundly changed genetic and breeding research in horticultural crops. High-quality reference genomes are now available for numerous fruit, vegetable, nut, ornamental, and plantation crops, facilitating the identification of quantitative trait loci (QTLs), genome-wide association studies (GWAS), marker-assisted selection,

genomic selection, and functional characterization of genes controlling economically important traits. Nevertheless, most conventional genomic analyses continue to depend on a single linear reference genome.

The principal limitation of this approach is straightforward: a reference genome represents one individual or genotype rather than the entire genomic diversity of a species. Plant pangenome studies have demonstrated that substantial portions of genomic diversity can be absent from any individual reference assembly and that variable genomic regions frequently contain genes associated with adaptation, resistance, secondary metabolism, and other agronomically important functions (Schreiber et al., 2024).

This limitation is especially important in horticultural crops because many perennial fruit and nut species are highly heterozygous, clonally propagated, self-incompatible, polyploid, or derived from complex interspecific hybridization and introgression events. Tree fruit and nut crops are therefore considered particularly suitable systems for pangenomic analysis, as their genomes often contain extensive allelic and structural diversity that cannot be adequately represented by a single reference sequence (Labbancz and Dhingra, 2025).

Genetic variation relevant to crop improvement includes not only single-nucleotide polymorphisms (SNPs) and small insertions and deletions but also large insertions, deletions, inversions, duplications, translocations, copy-number variations (CNVs), presence–absence variations (PAVs), transposable-element insertions, and other complex structural variants (SVs). These variants may influence entire genes, gene dosage, promoter activity, chromatin organization, transcription, and metabolic pathways and can therefore have considerable effects on horticulturally important phenotypes (Schreiber et al., 2024).

One of the clearest demonstrations of this limitation was provided in tomato. Gao et al. (2019) constructed a tomato pangenome using genome sequences from 725 representative accessions and identified 4,873 genes absent from the conventional reference genome. The study further demonstrated that a rare promoter allele of TomLoxC affected apocarotenoid production and contributed to desirable tomato flavor. Thus, genetic information of direct breeding value would have been incompletely represented if analyses had remained restricted to the original tomato reference genome (Gao et al., 2019).

Pangenomics therefore represents a transition from the concept of “the reference genome” toward a genomic representation of the diversity occurring within a population, species, or genus. Graph genomes further advance this concept by allowing alternative sequences and haplotypes to coexist within a common reference framework (Garrison et al., 2024).

This review discusses the conceptual basis of pangenomes and graph genomes and evaluates their applications in horticultural crop improvement. Particular emphasis is placed on tomato, cucumber, grapevine, apple, citrus, kiwifruit, walnut, apricot, hazelnut, and strawberry. Pistachio, almond, and hawthorn are additionally discussed as horticulturally important crops with increasingly sophisticated genomic resources and strong potential for future pangenome development.

2. From a Single Reference Genome to the Pangenome

A conventional reference genome represents the chromosomes of one selected genotype as linear DNA sequences. Genomic reads obtained from other individuals are aligned against this reference, and differences are subsequently identified relative to the reference genotype.

This system is effective for detecting SNPs and relatively small indels within conserved regions. However, it becomes increasingly problematic when the analyzed genotype contains sequences absent from the reference or when extensive structural rearrangements exist. Such sequences may map incorrectly, show reduced mapping efficiency, or remain completely unmapped, creating reference bias (Schreiber et al., 2024).

A pangenome can broadly be defined as the collective genomic repertoire represented by multiple individuals of a species or related group. The gene content of a pangenome is generally separated into a core genome, containing genes present in all or nearly all individuals, and a variable or dispensable genome, containing genes found only in a subset of individuals. Some studies additionally identify accession-specific or private genes (Schreiber et al., 2024; Labbancz and Dhingra, 2025).

This distinction is biologically important. Genes involved in fundamental cellular processes are often enriched in core genomic regions, whereas variable regions may contain genes associated with environmental adaptation, pathogen recognition, secondary metabolism, and other rapidly evolving functions.

Pangenomes can be constructed using several approaches. Early plant pangenomes frequently used a reference-based strategy in which sequences that could not be aligned to the original reference were assembled and added to the reference genome. Modern approaches increasingly employ multiple high-quality de novo genome assemblies and therefore characterize both gene-content variation and chromosome-scale structural variation.

Recent advances in PacBio HiFi, Oxford Nanopore sequencing, and Hi-C chromosome scaffolding have greatly improved the feasibility of obtaining haplotype-resolved chromosome-scale genomes. Such resources are particularly valuable for horticultural species, many of which possess high levels of heterozygosity (Labbancz and Dhingra, 2025).

A further extension of the concept is the super-pangenome or metapangenome, in which genomes from cultivated species and related wild taxa are incorporated into a common genomic framework. Such an approach is particularly relevant to horticultural breeding because wild relatives frequently retain alleles lost during domestication and modern selection.

Tomato provides an excellent example. Super-pangenome analyses incorporating wild and cultivated *Solanum* species demonstrated extensive genomic diversity and structural variation across the tomato clade, identifying wild genetic resources with potential value for crop improvement (Li et al., 2023).

3. Graph Genomes and Structural Variation

Although a pangenome can be represented simply as a collection of genomic sequences or gene families, graph genomes provide a more powerful method for representing genomic diversity.

A conventional reference chromosome can be visualized as a single linear path. All individuals are analyzed relative to this path even when they possess sequences or genomic arrangements not present in the reference genotype.

In contrast, a graph genome contains interconnected sequence paths. Conserved genomic regions follow a common path, whereas alternative alleles, SNPs, insertions, deletions, inversions, duplications, and other structural variants create alternative branches. Each haplotype can therefore be represented as a particular path through the graph (Garrison et al., 2024).

Modern tools such as the PanGenome Graph Builder have been developed specifically to construct and analyze these genomic representations. Such methods permit relatively unbiased representation of multiple genomes and support downstream applications including read mapping, variant calling, visualization, and population-genomic analyses (Garrison et al., 2024).

The ability to represent SVs is particularly important. SVs typically include genomic changes larger than approximately 50 bp and can comprise insertions, deletions, inversions, translocations, duplications, and complex rearrangements. Unlike individual SNPs, SVs may alter complete genes, regulatory regions, or multiple genes simultaneously.

Consequently, structural variation can explain phenotypic variation that remains poorly captured in SNP-centered genomic studies. Pangenomic analysis therefore creates a conceptual shift from SNP-centered genomics toward a broader variome-centered approach, in which SNPs, indels, PAVs, CNVs, SVs, and haplotypes are analyzed together.

4. Pangenomics in Major Horticultural Crops

4.1. Tomato

Tomato (*Solanum lycopersicum*) is currently one of the most advanced horticultural models for pangenomic research.

Gao et al. (2019) constructed a pangenome using 725 phylogenetically and geographically representative tomato accessions. The analysis revealed 4,873 protein-coding genes absent from the conventional reference genome, demonstrating substantial gene-content diversity within tomato germplasm. Presence–absence variation analysis further indicated gene loss during domestication and improvement, particularly among genes associated with disease resistance (Gao et al., 2019).

One of the most important findings involved TomLoxC, which encodes a lipoxygenase associated with production of flavor-related compounds. A rare promoter allele that had declined during domestication was associated with changes in TomLoxC expression and apocarotenoid accumulation, illustrating the direct value of pangenomic information for fruit-quality improvement (Gao et al., 2019).

A major advance subsequently came from Zhou et al. (2022), who constructed a tomato graph pangenome from more than 19 million variants identified across 838 genomes, including 32 new reference-level assemblies. The graph was applied to 20,323 gene-expression and metabolite traits. Average estimated heritability increased from 0.33 with the linear reference genome to 0.41 with the graph pangenome, corresponding to an approximately 24% improvement (Zhou et al., 2022).

The additional heritability was attributed largely to improved detection of causal structural variants. The approach also enabled identification of candidate genes potentially contributing to soluble solid content, demonstrating that graph genomes can directly improve the detection of genetic factors underlying fruit-quality traits (Zhou et al., 2022).

These studies were followed by tomato super-pangenome analyses incorporating wild and cultivated species. Such resources revealed extensive structural variation and highlighted the potential of wild tomato relatives as sources of useful genetic variation for breeding (Li et al., 2023).

Thus, tomato illustrates the progression from a linear reference genome to a gene-based pangenome, graph pangenome, and finally a super-pangenome incorporating wild diversity.

4.2. Cucumber

Cucumber (*Cucumis sativus*) represents another important vegetable model for graph-based pangenomics. Li et al. (2022) generated chromosome-scale genome assemblies for 11 representative cucumber accessions and combined them with the previously available ‘9930’ genome to develop a graph-based pangenome consisting of 12 chromosome-scale assemblies. The selected material included both wild and cultivated cucumber accessions representing substantial genetic diversity (Li et al., 2022).

The resulting graph pangenome enabled detection of millions of genomic variants, including numerous structural variants, which were subsequently genotyped across a 115-line cucumber core collection. The study linked genomic variation with domestication and agronomic characteristics and demonstrated the value of graph-based representation for cucumber improvement (Li et al., 2022).

The cucumber pangenome was expanded considerably by Zhao et al. (2026). Their graph-based pangenomic analysis examined structural-variation dynamics during cucumber domestication and modern breeding. Importantly, structural-variant information was incorporated into genomic prediction, demonstrating that SV-based information can improve breeding models rather than simply serving as descriptive genomic data (Zhao et al., 2026).

Cucumber therefore provides a particularly useful example of the transition from variant discovery to variome-based genomic breeding.

4.3. Grapevine

Grapevine represents a particularly suitable crop for pangenomic analysis because of its high heterozygosity, extensive clonal propagation, long domestication history, and considerable diversity among cultivated and wild grape germplasm.

Liu et al. (2024) developed the graph-based grapevine pangenome Grapepan v.1.0 by integrating newly generated haplotype-resolved genome assemblies with previously published high-quality grape genomes. The resource provided a substantially improved representation of genomic diversity compared with individual linear reference genomes (Liu et al., 2024).

The study analyzed 466 grapevine accessions and generated a variation map containing approximately 8.59 million SNPs, more than 513,000 small indels, and 236,449 structural variants. These genomic data were integrated with phenotypic information for 29 complex agronomic traits and used in both GWAS and genomic prediction analyses (Liu et al., 2024).

The results demonstrated that SVs contribute significantly to quantitative genetic variation and that graph-based genomic information can enhance genomic breeding. Such approaches have direct potential for improving berry size, sugar–acid balance, fruit color, seedlessness, ripening time, disease resistance, and environmental adaptation.

The grapevine example is therefore particularly significant because it demonstrates how pangenome construction can move beyond genome description and become directly integrated into genomic-selection pipelines.

4.4. Apple

Apple (*Malus domestica*) and its related wild species possess considerable genetic and structural diversity due to extensive hybridization, domestication, and introgression.

Wang et al. (2023) generated de novo genome assemblies for 10 genetically diverse *Malus* accessions and combined them with three previously available genomes to construct a 13-accession Malus pangenome. The study identified 20,220 CNVs and 317,393 SVs, demonstrating extensive genomic variation within the genus (Wang et al., 2023).

A particularly interesting discovery involved a 209-bp insertion affecting the *MMK2* gene. The insertion generated a noncoding RNA capable of influencing gene expression and fruit coloration. Structural variants were also found in genomic regions associated with fruit-quality characteristics and biotic resistance (Wang et al., 2023).

The genomic representation of *Malus* diversity was expanded substantially by Li et al. (2025), who generated 30 high-quality genomes representing major evolutionary lineages of the genus. Their graph-based pangenome captured shared and species-specific structural variants and enabled the development of a molecular marker associated with apple scab resistance (Li et al., 2025).

The apple pangenome therefore demonstrates the potential of combining cultivated and wild germplasm for improving disease resistance, fruit pigmentation, quality characteristics, environmental adaptation, and other complex traits.

4.5. Citrus

Citrus has a particularly complex evolutionary history characterized by interspecific hybridization, introgression, and clonal propagation. These characteristics make the genus especially suitable for pangenomic analysis.

Huang et al. (2023) used genomic information from 314 accessions and generated new assemblies from multiple Aurantioideae species to develop a pangenomic representation of the orange subfamily. Their analysis provided important insight into citrus evolutionary history and the genetic basis of fruit acidity (Huang et al., 2023).

One of the major findings involved PH4, a regulatory gene contributing to citric acid accumulation. Genomic and functional analyses demonstrated that variation affecting PH4 played an important role in the evolution of citrus fruit acidity and therefore fruit taste (Huang et al., 2023).

This is particularly important from a horticultural perspective because organic-acid concentration strongly influences fruit flavor, processing characteristics, and consumer preference.

The citrus example demonstrates how pangenomic discovery can be connected directly to metabolic phenotype and subsequently validated through functional experiments.

4.6. Kiwifruit

Pangenomic resources have also been developed for kiwifruit.

Wang et al. (2024) constructed a graph-based pangenome of *Actinidia chinensis* using 14 chromosome-scale haplotype-resolved genome assemblies derived from seven representative cultivars or lines. The resulting pangenome included 49,770 nonredundant gene families and 84,591 nonredundant structural variants (Wang et al., 2024).

The graph-based representation improved identification of structural variation associated with fruit color and, particularly, fruit degreening during ripening.

This finding has clear postharvest significance. Chlorophyll degradation is one of the principal biochemical events associated with ripening and color development in many fruit species, while some kiwifruit genotypes maintain green flesh at maturity.

The study therefore demonstrates the potential of graph genomes for elucidating structural variation affecting postharvest and ripening-related phenotypes (Wang et al., 2024).

Future integration of kiwifruit pangenomic information with fruit firmness, ethylene production, soluble solids, organic acids, aroma volatiles, and storage behavior could substantially improve breeding for postharvest quality.

4.7. Walnut

Pangenomic approaches are also becoming increasingly important in perennial nut crops.
Comparative genomic and pangenomic analysis within *Juglans* has revealed substantial structural and gene-content variation relevant to disease resistance and fatty acid metabolism (Zhou et al., 2023).
More recently, Liu et al. (2025) developed a high-quality genome assembly of the Persian walnut cultivar 'Xiangling' and constructed a graph-based structural pangenome using eight *Juglans* genomes. The authors subsequently resequenced 285 walnut accessions and integrated genomic variation with GWAS and multiple omics datasets (Liu et al., 2025).
Particular attention was given to walnut shell thickness, an economically important trait. Candidate genes involved in secondary cell-wall development and lignin accumulation were identified, including genes belonging to the MYB, NAC, CESA, LAC, and lignin-biosynthesis pathways.
The study represents a particularly sophisticated example of pangenomics because genomic variation was combined with transcriptomic, metabolic, epigenetic, and other molecular data to investigate endocarp development (Liu et al., 2025).
Future walnut pangenomic studies could similarly address kernel percentage, shell strength, oil and fatty acid composition, phenolic compounds, disease resistance, and environmental adaptation.

4.8. Apricot

Apricot has rapidly emerged as an important pangenomic model among temperate fruit trees.
Tan et al. (2024) generated a haplotype-resolved genome of *Prunus zhengheensis* and developed a 242.22-Mb pangenome of the Armeniaca section using 13 chromosome-level genomes. The analysis revealed extensive structural variation and provided insight into cold adaptation within apricot germplasm (Tan et al., 2024).
A particularly important discovery was a 566-bp insertion in the promoter region of HSFA1d in *P. armeniaca*. Promoter analyses indicated increased activity under low-temperature conditions, while functional experiments supported a positive role for HSFA1d in chilling adaptation (Tan et al., 2024).
This result demonstrates how an SV identified through pangenomics can be linked directly to an environmental-adaptation phenotype.
The genomic representation of apricot diversity was expanded further by Blanchard et al. (2026), who constructed a phylogeny-driven Armeniaca metapangenome incorporating cultivated apricot and related wild species. Their analysis revealed extensive structural diversity and examined complex genomic regions associated with adaptation and domestication (Blanchard et al., 2026).
The study is particularly relevant to perennial-fruit breeding because structural variation around dormancy-related genomic regions may contribute to chilling requirement, dormancy release, flowering time, and climatic adaptation.
With increasing spring temperatures and irregular winter chilling, such traits are becoming increasingly important in apricot breeding.

4.9. Hazelnut

Hazelnut pangenomics has developed more recently but is now supported by increasingly high-quality genomic resources.
Brainard et al. (2024) generated chromosome-scale genome assemblies for two American hazelnut (*Corylus americana*) accessions, 'Rush' and 'Winkler'. Comparative analyses with other chromosome-scale *Corylus* genomes revealed extensive synteny together with important genomic rearrangements and provided a foundation for broader pangenomic analysis of the genus (Brainard et al., 2024).
Zheng et al. (2025) subsequently used pangenomic analysis to examine developmental variation of bracts among *Corylus* taxa. The study revealed structural genomic differences associated with variation in bract morphology and identified CUC3 as an important candidate gene associated with the development of spiny bracts (Zheng et al., 2025).

Although current *Corylus* pangenomic resources remain less extensive than those available for tomato, cucumber, grapevine, or apple, they establish an important genomic framework for future hazelnut breeding.

Population-scale graph pangenomes incorporating European hazelnut cultivars, traditional germplasm, *C. americana*, *C. heterophylla*, and other wild relatives could facilitate the identification of variants controlling nut size, kernel percentage, shell thickness, fatty acid composition, flowering phenology, disease resistance, and environmental adaptation.

4.10. Strawberry

The genus *Fragaria* represents an important pangenomic model among berry crops.

Qiao et al. (2021) generated chromosome-scale reference genomes for multiple strawberry species and resequenced a broad collection of *Fragaria* germplasm. These data were used to construct a Fragaria pangenome and investigate the evolutionary dynamics of gene families within the genus (Qiao et al., 2021).

The analysis revealed substantial variation in gene content among strawberry species and provided new insights into the evolutionary history of the genus.

The study also examined genetic variation associated with fruit coloration. Independent mutations affecting MYB10, a central regulator of anthocyanin biosynthesis, were associated with white-fruited phenotypes in different strawberry species (Qiao et al., 2021).

The available *Fragaria* pangenome is particularly valuable as a comparative genomic resource. However, an important distinction must be made between diploid *Fragaria* pangenomic resources and the considerably more complex genome of cultivated strawberry, *Fragaria* × *ananassa*, which is allo-octoploid.

Consequently, the construction of a broad, population-scale, haplotype-aware graph pangenome specifically representing cultivated octoploid strawberry remains an important direction for future research.

Such a resource could facilitate the discovery of SVs and haplotypes associated with fruit color, anthocyanin accumulation, soluble solids, sugars, organic acids, aroma, firmness, disease resistance, flowering behavior, and postharvest shelf life.

5. Current Status of Pangenomics in Selected Horticultural Crops

Crop	***Current genomic/pangenomic status***	***Major demonstrated or potential applications***
Tomato	Advanced pangenome, graph pangenome and super-pangenome	Flavor, soluble solids, metabolite composition, disease resistance
Cucumber	Advanced graph pangenome	Domestication, agronomic traits, structural variation, genomic prediction
Grapevine	Advanced graph pangenome	GWAS and genomic prediction for complex traits
Apple	Pangenome and genus-level graph pangenome	Fruit color, fruit quality, scab resistance, domestication
Citrus	Aurantioideae pangenome	Citric acid accumulation, fruit taste, evolutionary history
Kiwifruit	Graph-based pangenome	Fruit color and degreening
Walnut	Structural graph pangenome	Shell thickness, lignification, endocarp development
Apricot	Graph pangenome and metapangenome	Cold adaptation, dormancy, domestication
Hazelnut	Emerging *Corylus* pangenomic resources	Bract development and future nut-quality/resistance traits
Strawberry	*Fragaria* pangenome	Evolution, fruit pigmentation; octoploid crop pangenome remains a priority
Pistachio	High-quality chromosome-level genomes	Strong candidate for future population graph pangenome

Almond	Multiple high-quality and phased genomes	Strong candidate for future graph pangenome
Hawthorn	Chromosome-scale reference genomes	Strong candidate for genus-level pangenome

The overall pattern indicates that pangenomics is progressing rapidly in major horticultural crops, but the maturity of available resources varies substantially among species (Labbancz and Dhingra, 2025).

6. Applications of Pangenomics in Horticultural Crop Improvement

6.1. Discovery of Hidden Genetic Variation

One of the most important contributions of pangenomics is the recovery of genomic information absent from a conventional reference genome.

The tomato example demonstrates this clearly: thousands of genes were missing from the original reference genome but were recovered after sequencing genetically diverse germplasm (Gao et al., 2019). Similar principles apply to structural variants. Large insertions, deletions, duplications, inversions, and PAVs may be poorly detected when reads are mapped exclusively against one reference genotype.

These variants are particularly important when useful traits originate from landraces or wild relatives. Consequently, super-pangenomes may provide a more effective framework for introgressing wild alleles into cultivated horticultural crops (Li et al., 2023; Schreiber et al., 2024).

6.2. Improved GWAS and QTL Mapping

Most conventional GWAS analyses rely predominantly on SNP markers. Although highly informative, SNPs may not represent the actual causal variation underlying a phenotype.

Graph pangenomes allow structural variants to be directly genotyped and tested for association with phenotypic traits.

In tomato, incorporation of pangenome-derived variants increased estimated heritability and revealed candidate loci affecting soluble solid content that were not efficiently captured by the linear reference approach (Zhou et al., 2022).

Similarly, graph-based genomic resources have been incorporated into GWAS or trait-mapping analyses in cucumber, grapevine, apple, walnut, and other horticultural crops (Li et al., 2022; Wang et al., 2023; Liu et al., 2024; Liu et al., 2025).

Future horticultural GWAS should therefore increasingly integrate SNPs with structural variants, PAVs, CNVs, and haplotypes.

6.3. Fruit Quality and Biochemical Traits

Pangenomics has particularly strong potential for fruit-quality research.

Flavor, aroma, sugar concentration, organic-acid composition, pigments, phenolic compounds, firmness, and postharvest behavior are generally quantitative traits regulated by complex networks of metabolic and regulatory genes.

Several pangenomic studies have already demonstrated direct associations with biochemical fruit characteristics. The TomLoxC locus contributes to tomato flavor (Gao et al., 2019), variation involving PH4 affects citric acid accumulation in citrus (Huang et al., 2023), structural variants influence apple coloration (Wang et al., 2023), and structural variation contributes to fruit degreening in kiwifruit (Wang et al., 2024).

These findings demonstrate the potential value of combining graph-pangenome variation with biochemical profiling.

Future studies integrating pangenomics with HPLC, GC-MS, LC-MS, metabolomics, volatile profiling, pigment analysis, fatty-acid analysis, and antioxidant measurements may substantially improve our understanding of the genomic regulation of fruit and nut quality.

6.4. Postharvest Quality

Postharvest characteristics remain relatively underrepresented in current horticultural pangenomics, creating an important research opportunity.

Firmness loss, softening, ethylene response, water loss, chilling injury, browning, pathogen susceptibility, pigment degradation, aroma development, and storage-related metabolic changes all have substantial genetic components.
The kiwifruit graph pangenome represents an important early example because SVs were linked with fruit degreening during ripening (Wang et al., 2024).
Future studies could integrate graph-pangenome information with controlled storage experiments to identify genomic variants associated with shelf life, firmness retention, physiological disorders, antioxidant metabolism, cell-wall degradation, and postharvest disease resistance.
Such approaches could be especially valuable in strawberry, tomato, grape, apple, kiwifruit, citrus, and stone fruits.

6.5. Disease Resistance and Environmental Adaptation

Disease-resistance genes frequently occur in rapidly evolving and structurally variable genomic regions. Consequently, these regions can be difficult to characterize accurately using a single reference genome. Pangenomes allow resistance-gene presence–absence variation and copy-number variation to be characterized more efficiently, particularly when resistance originates from wild relatives (Schreiber et al., 2024).
Apple provides an important example because genus-level graph pangenomics facilitated the development of a marker associated with apple scab resistance (Li et al., 2025).
Environmental adaptation represents another major application. The apricot pangenome identified an HSFA1d promoter insertion associated with low-temperature response, providing evidence that structural variation can contribute directly to climatic adaptation (Tan et al., 2024).
Similar approaches could be used to investigate drought, salinity, heat, chilling requirement, winter dormancy, and spring frost tolerance in horticultural crops.

6.6. Genomic Selection

Genomic selection traditionally relies on thousands or millions of SNP markers distributed throughout the genome.
Pangenomic resources provide the opportunity to extend these models by incorporating SNPs, indels, SVs, CNVs, gene-content variation, and haplotypes.
The tomato graph-pangenome study demonstrated that structural variation could recover additional heritable variation (Zhou et al., 2022), while grapevine and cucumber studies have shown that graph-derived variants can be incorporated directly into genomic-prediction frameworks (Liu et al., 2024; Zhao et al., 2026).
These results point toward the emergence of pangenome-informed genomic selection, in which breeding values are predicted from a more complete representation of genomic diversity.

7. Research Gaps and Opportunities in Pistachio, Almond and Hawthorn

7.1. Pistachio

Pistachio (*Pistacia vera*) already possesses a strong genomic foundation.
Kafkas et al. (2023) generated chromosome-level genome assemblies for the female cultivar ‘Siirt’ and the male cultivar ‘Bağyolu’ and characterized the Z and W sex chromosomes. Their study provided important information on pistachio domestication, genomic evolution, and sex determination (Kafkas et al., 2023).
Earlier whole-genome and transcriptome studies also demonstrated substantial genomic diversity associated with adaptation and domestication in pistachio. Collectively, these resources create a strong foundation for the next step in pistachio genomics.
A comprehensive population-scale graph pangenome incorporating Turkish, Iranian, Central Asian, Mediterranean, and North American cultivars, together with wild *Pistacia* species, would have considerable breeding value.
Potential target traits include sex determination, flowering phenology, alternate bearing, blank nut formation, shell splitting, nut and kernel size, fatty acid composition, disease resistance, salinity tolerance, drought tolerance, and high-temperature adaptation.

Such a project would be particularly valuable because pistachio is characterized by substantial geographical and genetic diversity, while many commercially important traits remain difficult to improve through conventional breeding alone.

7.2. Almond

Almond (*Prunus dulcis*) is another strong candidate for graph-pangenome development.
Multiple reference genomes have already been published, and Castanera et al. (2024) developed a phased genome assembly of the highly heterozygous cultivar 'Texas'. Their study demonstrated extensive heterozygosity at SNP, small-indel, and structural-variant levels and showed that many SVs were associated with transposable-element insertions and allele-specific gene expression (Castanera et al., 2024).
Additional high-quality almond genomes continue to become available, further improving the genomic foundation for pangenome construction.
Almond is particularly suitable for this approach because traditional cultivars often possess high heterozygosity and self-incompatibility, while modern breeding has selected strongly for self-compatibility, delayed flowering, kernel characteristics, and productivity.
A future almond graph pangenome could integrate Mediterranean, Turkish, Iranian, Central Asian, European, and North American germplasm.
Important target traits would include self-compatibility, flowering date, frost tolerance, kernel sweetness or bitterness, shell hardness, double kernels, disease resistance, drought tolerance, and yield stability.

7.3. Hawthorn

Hawthorn (*Crataegus* spp.) also possesses increasingly sophisticated genomic resources.
Zhang et al. (2022) generated a chromosome-level genome for cultivated hawthorn *Crataegus pinnatifida* var. *major* 'Qiu Jinxing'. The assembled genome was approximately 823.41 Mb, with 779.24 Mb anchored to 17 pseudochromosomes and 40,571 predicted genes (Zhang et al., 2022).
The genome also revealed expansion of gene families associated with flavonoid and triterpenoid biosynthesis, two groups of compounds that are particularly important for hawthorn fruit quality and medicinal value (Zhang et al., 2022).
Given the extensive morphological, taxonomic, and biochemical diversity of *Crataegus*, a genus-level pangenome could provide an important new resource.
Future studies could target genetic variation controlling fruit size, color, soluble solids, organic acids, flavonoids, phenolics, triterpenoids, antioxidant capacity, seed characteristics, disease resistance, and adaptation to different environments.

8. Challenges of Pangenomics in Horticultural Crops

Despite its considerable potential, pangenomics still faces several biological and technical limitations.
The first is germplasm representation. The biological value of a pangenome depends strongly on which genotypes are included. Sequencing many genetically similar commercial cultivars may produce a large dataset but still fail to capture important diversity. Landraces, wild relatives, geographically distinct populations, and historically important cultivars should therefore be carefully selected (Schreiber et al., 2024).
Second, high-quality graph construction increasingly depends on long-read and haplotype-resolved genome assemblies. Such assemblies are becoming more affordable but remain substantially more demanding than conventional short-read resequencing.
Third, many horticultural crops possess extremely high heterozygosity. Others, such as cultivated strawberry, are polyploid. Correctly distinguishing homologous, homeologous, and haplotype-specific structural variants therefore remains technically difficult.
Fourth, graph genomes create substantial computational challenges. Construction, indexing, mapping, variant calling, and visualization require specialized software and significant computational resources (Garrison et al., 2024).
Fifth, identification of a genomic association does not demonstrate causality. Candidate structural variants must still be validated through qRT-PCR, transcriptomics, biochemical analyses, segregating populations, transient expression, transformation, or genome editing.

The citrus and apricot examples demonstrate the importance of this principle. Pangenomic discovery became substantially more valuable when genomic variants were experimentally connected with citric acid accumulation and cold adaptation, respectively (Huang et al., 2023; Tan et al., 2024).
Finally, phenotyping remains a critical limitation. Increasing genomic resolution cannot compensate for poorly characterized phenotypes. High-quality, reproducible phenotypic and biochemical measurements are therefore essential for successful pangenome-assisted breeding.

9. Future Perspectives: From Pangenomics to Panomics

The next major stage in horticultural pangenomics will probably involve a transition from structural pangenomes toward functional panomics.
Rather than asking only which genomic variants are present, future research will investigate how these variants influence transcription, protein abundance, metabolite accumulation, physiological responses, and ultimately economically important traits.
Graph-genome information can therefore be integrated with transcriptomics, epigenomics, proteomics, metabolomics, phenomics, and environmental data (Schreiber et al., 2024).
This approach could be especially powerful in horticultural quality research.
For example, genomic and structural variation could be integrated with measurements of:

- glucose, fructose, and sucrose;
- citric, malic, tartaric, and other organic acids;
- phenolic compounds;
- anthocyanins and carotenoids;
- volatile aroma compounds;
- fatty acids;
- antioxidant activity;
- soluble solids;
- firmness;
- fruit color;
- weight loss;
- storage disorders; and
- postharvest shelf life.

Such datasets would enable the identification of genomic haplotypes associated not simply with one phenotype but with complete quality profiles.
Artificial intelligence and machine learning may become increasingly important in this context because graph pangenomes generate enormous multidimensional datasets. Millions of SNPs, SVs, haplotypes, gene-expression values, metabolites, environmental measurements, and phenotypic observations may need to be analyzed simultaneously.
Machine-learning algorithms could therefore support identification of genomic features with high predictive value and improve modeling of genotype × environment interactions.
Another important application is genome editing.
CRISPR guide RNAs are frequently designed using a single reference genome. However, polymorphisms or structural variation in the target region can affect guide specificity and editing efficiency. A pangenome can reveal allelic diversity before target selection and therefore improve the design of genotype-independent or allele-specific genome-editing strategies.
The future pangenome-assisted breeding pipeline may therefore be summarized as:
Diverse germplasm → haplotype-resolved sequencing → graph-pangenome construction → SNP and SV discovery → high-quality phenotyping → multi-omics integration → GWAS/genomic prediction → functional validation → marker-assisted selection or genome editing → improved cultivar.
The value of future horticultural pangenomes will therefore depend not simply on their size but on how effectively genomic diversity can be connected with phenotype and translated into breeding decisions.

10. Conclusion

Pangenomics and graph genomes represent a fundamental transition in plant genomics from single-genotype reference sequences toward population-, species-, and genus-level representations of genomic diversity.

This transition is particularly important for horticultural crops because many fruit and nut species are highly heterozygous, clonally propagated, polyploid, interspecific hybrids, or products of complex domestication and introgression histories (Schreiber et al., 2024; Labbancz and Dhingra, 2025).

Studies in tomato, cucumber, grapevine, apple, citrus, kiwifruit, walnut, apricot, hazelnut, and strawberry demonstrate that pangenomic approaches can reveal genes and structural variants poorly represented or completely absent from conventional reference genomes.

Importantly, these variants are no longer merely catalogued. Pangenome-derived variation has already been associated with tomato flavor and soluble solids, citrus acidity, apple pigmentation and disease resistance, kiwifruit degreening, walnut shell development, apricot cold adaptation, and multiple agronomic traits in cucumber and grapevine (Gao et al., 2019; Zhou et al., 2022; Li et al., 2022; Huang et al., 2023; Wang et al., 2023; Wang et al., 2024; Liu et al., 2024; Liu et al., 2025).

The next major challenge is therefore not simply to generate increasingly large pangenomes but to connect genomic diversity with accurately measured phenotypes and practical breeding outcomes.

At the same time, economically important horticultural crops such as pistachio, almond, and hawthorn already possess genomic resources that make them attractive targets for future population-scale graph-pangenome development (Zhang et al., 2022; Kafkas et al., 2023; Castanera et al., 2024). (ScienceDirect)

Integration of pangenomics with GWAS, genomic selection, high-throughput phenotyping, transcriptomics, metabolomics, artificial intelligence, and genome editing is expected to establish a new generation of pangenome-informed precision breeding.

Such approaches could enable breeders to utilize cultivated and wild genomic diversity more efficiently to improve fruit and nut quality, yield, disease resistance, environmental adaptation, and postharvest performance.

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ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING APPLICATIONS IN FRUIT BREEDING AND QUALITY PREDICTION: CURRENT ADVANCES AND FUTURE PERSPECTIVES

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ÖZET
Meyve ıslahı ve kalite değerlendirmesi; genotip, çevre, fizyoloji ve biyokimyasal bileşim arasındaki karmaşık etkileşimlerden etkilenen, giderek daha fazla veriye dayalı süreçlerdir. Genomik, yüksek verimli fenotipleme, uzaktan algılama, hiperspektral görüntüleme ve multi-omik teknolojilerindeki gelişmeler, çok boyutlu veri setlerinin oluşmasına yol açmış; bu durum yapay zekâ (AI), makine öğrenmesi (ML) ve derin öğrenme (DL) yaklaşımlarının meyve ıslahında kullanımını artırmıştır. Bu derlemede AI ve ML'nin genomik seleksiyon, yüksek verimli fenotipleme, meyve tespiti ve sayımı, biyokimyasal özelliklerin modellenmesi, tahribatsız kalite analizi, hiperspektral görüntüleme ve multi-omik veri entegrasyonundaki güncel uygulamaları değerlendirilmiştir. Görüntü tabanlı fenotipleme meyve sayısı, büyüklüğü, şekli ve olgunluk durumunun hızlı belirlenmesini sağlarken, hiperspektral ve spektroskopik yöntemlerin ML ile entegrasyonu sertlik, SÇKM, asitlik ve bazı biyokimyasal özelliklerin tahribatsız tahminine olanak sağlamaktadır. Bununla birlikte veri yetersizliği, aşırı öğrenme, model aktarılabilirliği, açıklanabilirlik ve bağımsız doğrulama eksikliği önemli sınırlamalardır. Gelecekte multimodal fenotipleme, açıklanabilir yapay zekâ ve multi-omik veri entegrasyonunun meyve ıslahı ve kalite tahmininde daha önemli rol oynaması beklenmektedir.
Anahtar Kelimeler: Yapay Zekâ, Makine Öğrenmesi, Meyve Islahı, Meyve Kalitesi, Genomik Seleksiyon, Hiperspektral Görüntüleme, Multi-Omik

ABSTRACT
Fruit breeding and quality assessment are increasingly data-driven processes influenced by the complex interactions between genotype, environment, physiology, and biochemical composition. Advances in genomics, high-throughput phenotyping, remote sensing, hyperspectral imaging, and multi-omics technologies have led to the creation of multidimensional datasets, increasing the use of artificial intelligence (AI), machine learning (ML), and deep learning (DL) approaches in fruit breeding. This review summarizes the current applications of AI and ML in genomic selection, high-throughput phenotyping, fruit detection and counting, modeling of biochemical traits, non-destructive quality analysis, hyperspectral imaging, and multi-omics data integration. Image-based phenotyping enables fast evaluation of fruit number, size, shape, and maturity status. In addition, hyperspectral and spectroscopic techniques combined with ML can be used to estimate firmness, soluble solids content (SSC), acidity, and some biochemical traits in a non-destructive manner. However, important limitations are data scarcity, over-learning, model transferability, explainability and lack of independent validation. In the future, multimodal phenotyping, explainable artificial intelligence, and multi-omics data integration are expected to play a more important role in fruit breeding and quality prediction.
Keywords: Artificial Intelligence, Machine Learning, Fruit Breeding, Fruit Quality, Genomic Selection, Hyperspectral Imaging, Multi-Omics.

1. Introduction
Fruit breeding programs primarily aim to develop new cultivars characterized by high yield, superior fruit quality, resistance to diseases and pests, tolerance to abiotic stresses, extended shelf life, and adaptation to diverse environmental conditions. However, particularly in woody and perennial fruit crops, long juvenile periods, high heterozygosity, large plant size, and the polygenic inheritance of many economically important traits make breeding programs lengthy, labor-intensive, and costly.

Although advances in genomics and multi-omics technologies have enabled the generation of large volumes of molecular data, phenotyping remains one of the major bottlenecks in modern fruit breeding (Pacheco-Ruiz et al., 2025; Lee et al., 2024).

The challenge in modern fruit breeding is no longer limited to data generation. Genome sequencing and SNP genotyping can produce thousands or even millions of molecular variables, while transcriptomic, metabolomic, physiological, environmental sensor, and imaging technologies generate additional layers of heterogeneous data. Transforming these diverse datasets into biologically meaningful and practically applicable breeding decisions requires advanced analytical approaches (Pacheco-Ruiz et al., 2025).

Machine learning encompasses computational approaches that identify relationships, patterns, and interactions within datasets to generate classification or prediction models. Random Forest (RF), Support Vector Machine/Regression (SVM/SVR), k-nearest neighbors (KNN), gradient boosting, artificial neural networks (ANN), convolutional neural networks (CNN), and other deep-learning architectures are increasingly being applied in horticultural research. Deep learning has become particularly important in image-based phenotyping, disease diagnosis, fruit detection, maturity classification, and fruit quality assessment (Yang & Xu, 2021).

High-throughput phenotyping (HTP) systems integrate RGB cameras, multispectral and hyperspectral sensors, LiDAR, thermal cameras, unmanned aerial vehicles (UAVs), and other proximal sensing technologies to evaluate large breeding populations rapidly and objectively. In crops such as strawberry, where large numbers of individuals must be evaluated, automated image-based phenotyping has considerable potential to increase selection intensity and measurement accuracy while reducing the limitations associated with manual phenotyping (Zheng et al., 2021; James et al., 2022).

The objective of this review is to provide an integrated assessment of current AI, ML, and DL applications in fruit breeding and quality prediction, with particular emphasis on genomic selection, high-throughput phenotyping, computer vision, non-destructive quality assessment, biochemical prediction, postharvest evaluation, robotic applications, and multi-omics integration.

2. Literature Selection Approach

This study was designed as a narrative review aimed at integrating major recent developments in the field rather than as a systematic meta-analysis. Peer-reviewed research articles and review papers published in international scientific journals were used as the primary sources of evidence. Preprints, theses, conference abstracts, editorials, and general web sources were excluded as scientific evidence.

The majority of the reviewed literature was published between 2020 and 2026. However, several earlier key studies were included to describe the development of Vis/NIR spectroscopy and hyperspectral imaging for fruit quality assessment. The principal concepts used to structure the literature included genomic selection, artificial intelligence, machine learning, deep learning, high-throughput phenotyping, computer vision, fruit quality, hyperspectral imaging, remote sensing, and multi-omics.

3. Genomic Selection and Machine Learning in Fruit Breeding

3.1. Role of Genomic Selection in Fruit Breeding

Genomic selection (GS) aims to predict the genetic value of individuals that have not yet been phenotypically evaluated by using genome-wide molecular markers. While conventional marker-assisted selection generally focuses on loci with relatively large effects, genomic selection considers the cumulative effects of markers distributed throughout the genome and therefore offers particular advantages for polygenic traits.

Lee et al. (2024) conducted a systematic scoping review of genomic selection applications in fruit and vegetable crops and evaluated 63 studies covering 25 crop groups. The authors reported the use of a wide range of statistical and machine-learning methods, including GBLUP, Bayesian approaches, ridge regression, LASSO, Random Forest, and SVM. Their findings highlighted the potential of genomic selection to improve selection efficiency, especially in fruit crops with long generation intervals.

In apple, Kostick et al. (2023) used 955 individuals and 977 high-quality SNPs to predict commercially important fruit quality traits, including fruit weight, red overcolor, firmness, crispness, soluble solids content, and titratable acidity. Moderate to high genomic predictive abilities were obtained for several traits, although performance depended on the trait, the structure of the training and testing populations, and the number of markers included.

Roth et al. (2020) evaluated fruit texture traits in 537 apple genotypes using 8,294 SNPs. Their study demonstrated that prediction accuracy for firmness and crispness depended not only on the statistical model but also on the composition of the training population and its genetic relationship with the target population.

Taken together, these studies indicate that genomic selection can provide substantial time advantages in perennial fruit breeding, where conventional phenotypic evaluation may require several years. However, the practical value of genomic prediction depends on successful validation in breeding materials rather than merely obtaining high cross-validation performance within the same population (Roth et al., 2020; Kostick et al., 2023; Lee et al., 2024).

3.2. More Complex Models Are Not Necessarily Better

The increasing popularity of deep learning has sometimes created the assumption that more complex algorithms will automatically provide superior genomic prediction. Recent evidence shows that this is not universally true.

Wang et al. (2026) evaluated 399 F_1 individuals of tetraploid Chinese cherry using whole-genome resequencing, genome-wide association studies, transcriptomic analysis, and genomic selection. A total of 44,384 high-confidence SNPs were used, and 13 statistical and machine-learning models were compared. BayesA and ridge regression outperformed multilayer perceptron and CNN models for several traits. The study also reported that predictive performance reached a plateau at approximately 5,000 informative SNPs (Wang et al., 2026).

These results demonstrate that the objective of model selection should not be to employ the most sophisticated algorithm available, but rather to identify the model that best matches the structure of the dataset and generalizes reliably to independent material. Particularly in datasets containing tens of thousands of molecular variables but relatively few genotypes, highly complex models may increase the risk of overfitting.

4. High-Throughput Phenotyping and Computer Vision

Phenotyping remains one of the primary limitations in converting genomic information into practical breeding decisions. Manual measurement of traits such as fruit number, diameter, color, maturity, flower number, or canopy characteristics across hundreds or thousands of individuals requires considerable labor and time.

High-throughput phenotyping combines imaging and sensor technologies with automated data-processing algorithms. RGB, multispectral and hyperspectral imaging, LiDAR, depth cameras, and UAV systems allow morphological and physiological traits to be measured rapidly and repeatedly. Zheng et al. (2021), with particular emphasis on strawberry production, highlighted the potential integration of high-resolution RGB, multispectral, hyperspectral, chlorophyll fluorescence, and LiDAR technologies for crop phenotyping and management.

Strawberry breeding provides an important example of this approach. James et al. (2022) emphasized that manual evaluation of large numbers of plants in commercial strawberry breeding represents a major limitation to efficient selection. Automated phenotyping can provide objective information for identifying families and individual plants that should be advanced to subsequent stages of evaluation. Traits such as fruit number, fruit shape, flowering characteristics, and plant morphology are particularly suitable for automated analysis.

Warman and Fowler (2021) similarly suggested that deep-learning-based high-throughput phenotyping could substantially contribute to plant reproductive biology and phenotype discovery. Automated characterization of traits such as fruit shape and size can facilitate more detailed investigations of genotype-to-phenotype relationships.

4.1. Fruit Detection, Counting, and Maturity Classification

One of the most important applications of CNN-based image analysis is the automatic detection and counting of fruits. From a breeding perspective, the value of this approach extends beyond simple yield estimation. Fruit number, crop load, size distribution, and uniformity of ripening can all be relevant selection criteria.

Afonso et al. (2020) used Mask R-CNN to detect and count tomato fruits from greenhouse images acquired under commercial production conditions.

The study demonstrated that automatic phenotypic data collection can be achieved using relatively inexpensive imaging systems under realistic cultivation conditions.
In strawberry, Zhou et al. (2020) applied an improved Faster R-CNN architecture to RGB images for fruit detection and plumpness assessment under greenhouse conditions. Such systems are relevant not only for automated harvesting but also for breeding programs because they allow yield components and fruit characteristics to be measured directly on plants.
Yang and Xu (2021) further demonstrated that CNN-based deep-learning models are increasingly being applied in horticultural crops for fruit detection, yield estimation, quality classification, and phenotyping at different developmental stages.

5. From Two-Dimensional Imaging to Three-Dimensional Localization and Robotic Harvesting

The development of computer vision in horticulture is progressing from identifying fruits in two-dimensional images toward accurately locating them in three-dimensional space. Although algorithms such as YOLO, Faster R-CNN, and Mask R-CNN can successfully detect fruits in 2D images, robotic harvesting requires information on their actual spatial coordinates.
Wang and Sun (2025) used cluster segmentation and stereo vision for three-dimensional localization of apples under complex orchard conditions. Their approach addressed practical challenges such as variable illumination, fruit overlap, and dense canopy structure and demonstrated the potential application of 3D localization systems in robotic harvesting.
Although robotic harvesting is primarily associated with production automation, its technological infrastructure also has important implications for breeding. The same robotic and 3D imaging systems can be used for high-throughput measurement of fruit position, cluster density, fruit distribution within the canopy, fruit size, and maturity. Consequently, digital breeding and robotic harvesting may increasingly share common sensing and data-processing platforms.
Krishnan et al. (2024a), in a review of agricultural robots and AI-based systems, emphasized that real-world applications of ML and DL for fruit detection, harvesting, and disease diagnosis must consider not only prediction accuracy but also hardware requirements, computational cost, and real-time processing capacity.

6. Machine Learning for Fruit Quality Prediction

Fruit quality is a multidimensional concept. In addition to morphological traits such as fruit weight and size, commercial and consumer quality is influenced by firmness, color, soluble solids content, pH, titratable acidity, sugars, organic acids, phenolic compounds, anthocyanins, antioxidant activity, volatile compounds, and fatty acid composition.
The complex and often nonlinear relationships among these characteristics make fruit quality prediction an appropriate application area for ML. Importantly, machine learning should not be considered a direct replacement for reliable laboratory analyses. Instead, reference data obtained from conventional analytical methods can be used to train predictive models that subsequently support rapid screening and prioritization of samples.

6.1. Modeling Biochemical Traits

Temizyürek et al. (2025) evaluated multidimensional biochemical datasets from walnut genotypes, including phenolic compounds, antioxidant capacity, protein, total oil, fatty acids, sugars, and organic acids. Decision Tree, SVR, KNN, Gradient Boosting, Multi-Layer Perceptron, and Linear Regression models were compared. The best-performing algorithm varied according to the biochemical trait being predicted, demonstrating that no single ML method can be assumed to be universally superior for all fruit quality characteristics.
This approach may offer important advantages for screening large germplasm collections. Detailed HPLC, GC-MS, or related analyses of every biochemical trait across hundreds or thousands of genotypes are expensive and labor-intensive. Well-validated ML models could therefore help prioritize genotypes for advanced laboratory analyses.
In sweet cherry, Aydın et al. (2025) integrated PCA, Random Forest, and SHAP approaches to investigate relationships between fruit characteristics and cracking index. DPPH antioxidant activity and anthocyanin content were among the variables that contributed strongly to cracking prediction.

The use of SHAP was particularly valuable because it allowed the direction and magnitude of each variable's contribution to the model to be interpreted rather than merely producing a prediction.

6.2. Preharvest Prediction of Fruit Quality from Physiological Data

Machine-learning approaches may also extend fruit quality assessment beyond postharvest measurements by predicting harvest quality from physiological information collected during fruit development.

Zeng et al. (2025) modeled relationships among leaf photosynthetic parameters, canopy structure, carbon-water-nitrogen metabolism, vitamin C, soluble sugars, titratable acidity, and sugar-to-acid ratio in 'Fuji' apple using a back-propagation neural network. Feature selection simplified the models and improved predictive performance for some quality variables. These results suggest that sensor-based and physiological measurements could become important inputs for preharvest fruit quality prediction.

7. Non-Destructive Fruit Quality Assessment

Many conventional fruit quality measurements are destructive. Firmness measurement by penetrometer, juice extraction for soluble solids and acidity determinations, and numerous biochemical analyses often damage or completely consume the fruit. This can be particularly disadvantageous in breeding materials where only a limited number of fruits may be available.

Vis/NIR spectroscopy and hyperspectral imaging provide opportunities to estimate internal fruit quality without physically destroying the sample. Wang et al. (2015) reviewed the potential of spectroscopy for non-destructive evaluation of soluble solids, acidity, firmness, dry matter, vitamin C, polyphenols, pigments, and other fruit quality attributes.

7.1. Hyperspectral Imaging and Machine Learning

Hyperspectral imaging combines spatial imaging information with spectral information. Consequently, it can provide information not only about external color and morphology but also about spectral characteristics associated with physical and chemical composition.

Zhang et al. (2024) analyzed 1,200 fruits from six pear cultivars using hyperspectral data collected between 398 and 1004 nm. Different preprocessing methods, wavelength-selection approaches, and machine-learning algorithms were compared for predicting firmness, soluble solids content, pH, color, and maturity. LS-SVM-based models showed good performance for quality prediction, while BPNN achieved more than 99% accuracy in discriminating the six pear cultivars.

Tziotzios et al. (2024) demonstrated that spectral information combined with ML regression models could be used for non-destructive estimation of key postharvest quality characteristics, including firmness and soluble solids content, in kiwifruit.

More recently, Sun et al. (2026) used linear-variable-filter hyperspectral imaging to develop common predictive models for acidity and firmness using a combined dataset containing apple, pear, and kiwifruit. Their results indicate that future systems may move beyond models developed for a single fruit species toward more general multi-species quality prediction platforms.

7.2. Hyperspectral Imaging and Deep Learning

In recent years, hyperspectral imaging has increasingly been integrated with deep-learning methods rather than relying exclusively on conventional chemometric approaches. Chen et al. (2025) reviewed the combined application of HSI and DL for quality and safety inspection of fruits and vegetables and concluded that the integration offers important advantages for internal quality, external quality, and safety assessment.

Nevertheless, Chen et al. (2025) also emphasized several remaining limitations, including equipment cost, model generalizability, limited dataset size, and the need for lightweight architectures suitable for real-time applications.

8. Prediction of Biochemical Traits from Images

One of the most emerging areas of AI-based fruit quality assessment is the prediction of biochemical classes directly from visual information.

Krishnan et al. (2024b) developed the *Fruit-In-Sight* deep-learning framework to predict classes of secondary metabolites from fruit and leaf images. Such studies demonstrate the possibility of establishing predictive relationships between visual phenotype and metabolic characteristics.

However, the transferability of such models across cultivars, environments, cameras, and developmental stages requires careful evaluation. Image-based metabolite prediction should therefore not yet be considered a direct substitute for HPLC, LC-MS, or related analytical methods.

A more realistic future application would be to use imaging models as preliminary screening tools. Thousands of genotypes could first be evaluated using image and spectral data, after which a smaller subset predicted to possess high levels of phenolic compounds, anthocyanins, or other desirable metabolites could be selected for detailed chromatographic analysis.

9. Postharvest Quality Assessment

Postharvest storage is a dynamic period during which fruit firmness, maturity, color, water loss, mechanical injury, and physiological disorders continuously change. One important advantage of AI-based non-destructive systems is that the same fruit or fruit batch can potentially be monitored repeatedly throughout storage.

Nouri et al. (2025) used image-based vibration response analysis to predict kiwifruit firmness. Natural frequency and damping-related parameters were extracted using image processing and subsequently used as inputs for an artificial neural network. The resulting model showed high predictive performance and demonstrated the potential of image-based mechanical response analysis for rapid and non-destructive firmness classification.

Automatic detection of decay, bruising, and other surface defects is another important postharvest AI application. Safari et al. (2024) reviewed ML- and DL-based methods for automated fruit damage assessment and highlighted increasing progress toward real-time classification systems and integration with mobile and embedded devices.

10. Multimodal Sensor Fusion

A single sensor is often insufficient to characterize all dimensions of fruit quality. RGB imaging is highly effective for surface color, shape, and visible defects, whereas hyperspectral imaging can provide information associated with internal composition. LiDAR and depth cameras provide three-dimensional structural information, while thermal sensors may reflect tissue temperature and water-related responses. Zheng et al. (2021) emphasized that combining high-resolution RGB, multispectral, hyperspectral, chlorophyll fluorescence, and LiDAR data could improve measurement of diverse phenotypic characteristics in strawberry.

The next stage of this development is not simply to collect different sensor measurements within the same experiment, but to integrate their outputs into unified multimodal ML models.

A future fruit breeding pipeline could therefore be conceptualized as:

RGB imaging + HSI + LiDAR/3D structure + physiological sensors + environmental data + genomic data → AI/ML → predicted phenotype and fruit quality

Such an approach could facilitate the transition from conventional single-trait selection to multidimensional precision selection.

11. Multi-Omics Integration and Artificial Intelligence

Fruit quality is not determined directly by DNA sequence alone. Genetic variation influences gene expression, protein abundance, and metabolite accumulation, which interact with physiological processes and environmental conditions to generate the observed phenotype.

A simplified representation of this relationship is:

Genome → Transcriptome → Metabolome → Physiology → Phenotype → Fruit Quality

However, environmental and management factors influence every stage of this pathway:

Genotype × Environment × Management → Molecular Responses → Metabolism → Phenotype → Quality

Pacheco-Ruiz et al. (2025) identified integration of genomics, metabolomics, high-throughput phenotyping, and ML-based bioinformatics as a major emerging direction in modern fruit breeding. Despite rapid advances in data generation, translating heterogeneous data layers into practical breeding decisions remains a significant bottleneck.

The study conducted by Wang et al. (2026) in Chinese cherry provides a recent example of such integration, combining whole-genome resequencing,

GWAS, transcriptome analysis, and genomic prediction within a single research framework. Such approaches can potentially answer not only which individuals are superior but also which molecular mechanisms contribute to their superior performance.

12. Explainable Artificial Intelligence

High predictive accuracy alone is insufficient for fruit breeding. Understanding why a model classifies a particular genotype as superior is also important for biological interpretation and breeding decisions. Complex algorithms such as deep neural networks can achieve strong predictive performance but are frequently considered "black-box" models. Feature importance, permutation importance, and Shapley Additive Explanations (SHAP) provide tools for interpreting the contribution of individual variables to model predictions.

The combined PCA, Random Forest, and SHAP framework applied to sweet cherry provides a useful example. Aydın et al. (2025) showed that fruit cracking behavior could be interpreted not only through physical characteristics but also through contributions from biochemical variables.

In future genomic prediction research, it may therefore be more valuable to identify genomic regions that contribute strongly to model decisions and understand their biological functions rather than simply identifying SNP combinations associated with high prediction accuracy.

13. Representative Applications of AI and ML in Fruit Research

Crop/Application	*Data Type*	*AI/ML Approach*	*Target Trait*	*Main Outcome*
Apple	SNP + phenotype	Genomic prediction	Weight, color, firmness, SSC, acidity	Useful predictive performance for several traits (Kostick et al., 2023)
Apple	8,294 SNPs + texture	Genomic selection	Firmness and crispness	Training population structure was critical (Roth et al., 2020)
Chinese cherry	WGS + GWAS + RNA-seq	13 prediction models	Fruit quality traits	Some linear models outperformed DL approaches (Wang et al., 2026)
Walnut	HPLC/GC + biochemical data	DT, SVR, KNN, GB, MLP	Biochemical characteristics	Best model depended on the target trait (Temizyürek et al., 2025)
Sweet cherry	Physical + biochemical data	RF + SHAP	Cracking	Important predictors identified using explainable ML (Aydın et al., 2025)
Apple	Physiology + canopy traits	BP neural network	Sugars, acidity, vitamin C	Preharvest quality prediction was feasible (Zeng et al., 2025)
Pear	HSI	LS-SVM, BPNN	Firmness, SSC, pH, color	Successful non-destructive prediction and cultivar discrimination (Zhang et al., 2024)
Kiwifruit	Spectral data	ML regression	Firmness and SSC	Non-destructive postharvest evaluation achieved (Tziotzios et al., 2024)
Apple-pear-kiwifruit	HSI	Spectral index models	Firmness and acidity	Multi-species predictive model developed (Sun et al., 2026)

Strawberry	RGB images	Faster R-CNN	Fruit detection and plumpness	Potential for automated phenotyping demonstrated (Zhou et al., 2020)
Kiwifruit	Imaging + vibration	ANN	Firmness	Non-destructive firmness prediction achieved (Nouri et al., 2025)
Apple	Stereo imaging	3D computer vision	Fruit localization	Localization suitable for robotic harvesting (Wang & Sun, 2025)

14. Major Limitations

14.1. Limited Dataset Size

One of the major limitations of agricultural ML research is insufficient sample size. Genomic studies may contain tens of thousands of SNPs but only several hundred genotypes, while hyperspectral datasets may include hundreds of wavelengths for each individual sample. This creates the well-known "large p, small n" problem.

Feature selection, regularization, dimensionality reduction, data augmentation, and appropriate cross-validation are therefore essential. However, synthetically augmented data or random partitioning of observations from the same experiment cannot substitute for genuine independent validation.

14.2. Overfitting

A model may learn the training dataset extremely well while performing poorly on new biological material. Consequently, high R^2 or classification accuracy obtained from small and homogeneous datasets should be interpreted cautiously.

One of the most important questions for any breeding model should therefore be:

Can the model maintain similar predictive performance in previously unseen genotypes, different years, and independent locations?

Results from Roth et al. (2020), Kostick et al. (2023), and Wang et al. (2026) demonstrate why the structure of the training population and its genetic relationship with the target material require careful consideration.

14.3. Genotype × Environment Interaction

Light intensity, temperature, water availability, mineral nutrition, fruit position, canopy architecture, and management practices can strongly influence phenotype under orchard and field conditions. Consequently, the same genotype may exhibit different visual or spectral characteristics under different environments.

Models developed under controlled conditions may therefore lose accuracy when transferred to commercial orchards or different environmental conditions (Zheng et al., 2021; Yang & Xu, 2021).

14.4. Domain Shift

A model trained using one camera, location, cultivar, or environmental condition may not provide the same level of performance when transferred to another system. Recent reviews of agricultural AI identify data diversity, model generalization, and regional dataset bias as major challenges (Xu et al., 2026).

14.5. Model Interpretability

Models with high predictive accuracy but poorly understood decision processes may have limited scientific value for breeding. Explainable AI approaches should therefore become more common in genomic, metabolomic, and phenomic prediction studies (Aydın et al., 2025).

15. Future Perspectives

The next stage of AI implementation in fruit breeding is unlikely to consist merely of applying increasingly complex algorithms to single data types. Instead, progress will depend on integration of biological and technological information from multiple sources.

15.1. Multimodal Phenotyping
Combining RGB, HSI, multispectral imaging, LiDAR, thermal imaging, and physiological sensors will allow researchers to characterize whole-plant phenotypes rather than individual fruit traits. Zheng et al. (2021) emphasized the potential of sensor fusion for more reliable assessment of complex phenotypic characteristics.

15.2. Integration of Genomic and Phenomics Prediction
Combining genomic prediction with image and sensor information may improve selection accuracy in young plants for which conventional fruit phenotypes are not yet available. Such approaches may be particularly valuable for shortening breeding cycles in long-juvenile fruit species (Lee et al., 2024; Pacheco-Ruiz et al., 2025).

15.3. Multi-Omics AI
Integration of genomic, transcriptomic, and metabolomic data with ML may allow predictive models to become biologically interpretable rather than purely statistical. The genomic, GWAS, and transcriptomic integration demonstrated in Chinese cherry by Wang et al. (2026) represents an important example of this emerging direction.

15.4. Explainable AI
Wider use of SHAP and related approaches may enable researchers to determine which SNPs, metabolites, spectral bands, or morphological traits contribute most strongly to model predictions. The explainable framework applied by Aydın et al. (2025) in sweet cherry illustrates the potential of such methods in fruit quality studies.

15.5. Transfer Learning and Domain Adaptation
Adapting models trained on one fruit crop, cultivar, or location to new materials using relatively small additional datasets could reduce the need to generate large training datasets from scratch. Yang and Xu (2021) and Xu et al. (2026) identified generalization across environments and imaging systems as a major future challenge for DL in horticultural applications.

15.6. Lightweight and Real-Time Models
For practical orchard deployment, prediction accuracy alone is not sufficient. Computational efficiency is also essential. Lightweight models capable of running in real time on sensors, mobile devices, or agricultural robots are likely to become increasingly important. Chen et al. (2025) identified model size and computational requirements as major barriers to real-time implementation of HSI and DL systems.

15.7. Robotic Phenotyping
Fruit detection, segmentation, and 3D localization technologies developed for robotic harvesting can also be used for automated breeding phenotyping. A robot could potentially record fruit number per plant, size distribution, color, maturity, spatial distribution, and other phenotypic characteristics while simultaneously carrying out routine orchard operations (Wang & Sun, 2025).

16. Conclusion
Artificial intelligence and machine learning have become powerful tools that complement conventional statistical methods in fruit breeding and quality assessment. Genomic selection offers particular promise for early prediction of quantitative traits such as fruit weight, texture, color, soluble solids content, and acidity (Roth et al., 2020; Kostick et al., 2023). However, recent research also demonstrates that model complexity alone does not guarantee improved performance and that well-optimized linear approaches may outperform deep-learning models in some genomic datasets (Wang et al., 2026).

High-throughput phenotyping and computer vision have considerable potential to reduce major bottlenecks associated with manual phenotyping. Technological developments now range from fruit counting and maturity classification using RGB images to non-destructive internal quality prediction using hyperspectral imaging and three-dimensional localization for robotic harvesting (Afonso et al., 2020; Zheng et al., 2021; James et al., 2022; Wang & Sun, 2025).

The integration of hyperspectral imaging and ML is particularly promising for rapid and non-destructive estimation of firmness, soluble solids content, pH, acidity, and other fruit quality characteristics (Tziotzios et al., 2024; Zhang et al., 2024; Chen et al., 2025; Sun et al., 2026).

One of the most important potential applications in fruit breeding is the rapid preliminary screening of thousands of genotypes before selecting a smaller subset for advanced laboratory analyses.
Future fruit breeding systems are unlikely to rely exclusively on either genomic information or image analysis. A more powerful framework can be represented as:

Genomics + Transcriptomics + Metabolomics + Phenotyping + Imaging + Environmental Data + Artificial Intelligence

For this framework to become operational in practical breeding programs, major issues related to data standardization, adequate sample size, independent validation, transferability across environments, and model interpretability must be addressed. Successful integration of these approaches has the potential to accelerate the development of high-quality, climate-resilient, and commercially valuable fruit cultivars while making breeding decisions more objective, efficient, and data-driven.

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TUZ STRESİNİN YÖNETİMİNDE BİYOSTİMÜLANLAR: FİZYOLOJİK VE BİYOKİMYASAL YAKLAŞIMLAR

BIOSTIMULANTS IN SALT STRESS MANAGEMENT: PHYSIOLOGICAL AND BIOCHEMICAL APPROACHES

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ÖZET

Tuzluluk, bitkisel üretimde büyüme, verim ve ürün kalitesini sınırlandıran önemli abiyotik stres faktörlerinden biridir. Yüksek tuz konsantrasyonu başlangıçta kök bölgesinde ozmotik stres oluştururken, stresin devamında Na^+ ve Cl^- iyonlarının birikimi, iyon homeostazının bozulması ve reaktif oksijen türlerinin (ROS) aşırı üretimi sonucunda fizyolojik ve biyokimyasal hasarlar ortaya çıkmaktadır. Son yıllarda biyostimülanlar, bitkilerin stres koşullarındaki performansını destekleyen ve sürdürülebilir üretim sistemlerinde kullanılabilecek tamamlayıcı uygulamalar olarak öne çıkmaktadır. Bu çalışmada, biyostimülanların tuz stresinin yönetimindeki rolü güncel literatür doğrultusunda değerlendirilmiştir. Mikrobiyal biyostimülanlar, özellikle bitki gelişimini teşvik eden rizobakteriler (PGPR), alg ve bitki ekstraktları ile doğal ve aminoasit/protein temelli biyostimülanların bitkilerde oluşturduğu fizyolojik ve biyokimyasal yanıtlar karşılaştırmalı olarak incelenmiştir. Literatür bulguları, biyostimülan uygulamalarının kök gelişimi, su ilişkileri, fotosentetik aktivite ve biyokütle oluşumunu destekleyebildiğini; aynı zamanda Na^+/K^+ dengesinin korunması, ozmotik düzenleyicilerin birikimi ve antioksidan savunma sisteminin aktivasyonu yoluyla tuz stresinin olumsuz etkilerini sınırlandırabildiğini göstermektedir. Özellikle SOD, CAT, APX ve GR gibi antioksidan enzimlerin aktivitesindeki değişimler ile prolin ve çözünebilir şekerlerin birikimi, biyostimülanların stres yanıtındaki önemli göstergeleri olarak öne çıkmaktadır. Güncel araştırmalarda biyostimülan uygulamalarının H_2O_2, MDA ve elektrolit sızıntısını azaltabildiği, K^+/Na^+ oranını iyileştirebildiği ve fotosentetik performansın korunmasına katkı sağlayabildiği bildirilmektedir. Bununla birlikte biyostimülanların etkinliğinin biyostimülanın kaynağı ve bileşimi, uygulama dozu ve yöntemi, bitki türü/genotipi ile tuzluluk düzeyine bağlı olarak değiştiği görülmektedir. Sonuç olarak biyostimülanlar, tuzluluğu ortadan kaldıran bağımsız bir çözümden ziyade, bitkinin fizyolojik ve biyokimyasal stres toleransını güçlendiren tamamlayıcı bir yaklaşım olarak değerlendirilmelidir.

Anahtar Kelimeler: Tuz stresi, biyostimülanlar, ozmotik düzenleme, antioksidan savunma, Na^+/K^+ homeostazı, bitki fizyolojisi.

ABSTRACT

Salinity is one of the significant abiotic stress factors limiting growth, yield, and product quality in plant production. High salt concentrations initially induce osmotic stress in the root zone, while the accumulation of Na^+ and Cl^- ions, disruption of ionic homeostasis, and excessive production of reactive oxygen species (ROS) lead to physiological and biochemical damage. In recent years, biostimulants have emerged as complementary applications that support plant performance under stress conditions and can be used in sustainable production systems. In this study, the role of biostimulants in the management of salt stress was evaluated based on the current literature. The physiological and biochemical responses of plants to microbial biostimulants, particularly plant growth-promoting rhizobacteria (PGPR), algae and plant extracts, and natural and amino acid/protein-based biostimulants were comparatively examined. Literature findings indicate that biostimulant applications can support root development, water relations, photosynthetic activity, and biomass accumulation.

They have also been shown to maintain Na^+/K^+ balance, promote the accumulation of osmotic regulators, and activate the antioxidant defense system, thereby limiting the negative effects of salt stress. In particular, changes in the activities of antioxidant enzymes such as SOD, CAT, APX, and GR, along with the accumulation of proline and soluble sugars, are considered important indicators of the plant stress response to biostimulant application. Current research reports that biostimulant applications can reduce H_2O_2, MDA, and electrolyte leakage, improve the K^+/Na^+ ratio, and contribute to the maintenance of photosynthetic performance. However, the effectiveness of biostimulants varies depending on the source and composition of the biostimulant, application dose and method, plant species/genotype, and salinity level. In conclusion, biostimulants should be considered not as an independent solution that eliminates salinity, but rather as a complementary approach that strengthens the physiological and biochemical stress tolerance of plants.
Keywords: Salt stress, biostimulants, osmotic regulation, antioxidant defense, Na^+/K^+ homeostasis, plant physiology.

GİRİŞ

İklim değişikliği bitkilerin çok sayıda abiyotik stres faktörüne (sel, kuraklık, tuzluluk vb.) maruz kalmasına neden olmaktadır (Arora, 2019; Gowdy, 2020). Bu abiyotik stresler, ekonomik açıdan önemli türler için bitkisel üretimi sınırlayan başlıca faktörlerden biridir (Ramadoss, Lakkineni, Bose, Ali ve Annapurna, 2013) ve verim açığının neredeyse %70'ine katkıda bulunurlar (Rouphael ve Colla, 2020). Tuzluluk, bitkilerin fizyolojik işleyişini çeşitli şekillerde olumsuz etkileyen ve sonuç olarak bitkisel üretimde verim kaybına yol açan önemli abiyotik stres faktörlerinden biridir. Tuzluluk, toprak veya su içerisindeki tuz miktarını ifade etmekte (Arif, Singh, Siddiqui, Bajguz ve Hayat, 2020); yağış, kayaçların ayrışması ve rüzgâr gibi doğal süreçler sonucunda ortaya çıkan birincil tuzluluk ve aşırı sulama, ormansızlaşma ve arazilerin bitkisel örtüden arındırılması gibi antropojenik faaliyetler sonucunda oluşan ikincil tuzluluk olmak üzere iki gruba ayrılmaktadır (Munns and Tester, 2008; Arif, Singh, Siddiqui, Bajguz ve Hayat, 2020).

Tuzluluk, toprak çözeltisinin elektriksel iletkenliği (EC) ile ifade edilmekte ve EC değeri 4 dS m^{-1} veya üzerinde olan topraklar genellikle tuzlu olarak tanımlanmaktadır; bu değer yaklaşık 40 mM NaCl'ye eşdeğer olup, yaklaşık 0,2 MPa'lık bir osmotik basınç oluşturmaktadır (Munns ve Tester, 2008). Sodyum iyonları (Na+) tuzluluğa en büyük katkıyı sağlayan unsurlar olarak kabul edilirken; Cl^-, Mg^{2+}, SO_4^{2-} veya HCO_3^- iyonları da daha düşük düzeyde de olsa toprak tuzluluğunda rol oynamaktadır (Munns ve Tester, 2008; Zörb, Geilfus ve Dietz, 2019). Bu tuzların yüksek konsantrasyonları; reaktif oksijen türlerinin (ROS) oluşumu, hücre/yaprak genişlemesinde azalma, yaprak dökümü, su potansiyelinde (ψw) düşüş, membran potansiyelinde bozulma, membran hasarı, fotosentez hızlarında değişim, stoma kapanması, proteinlerin kararsızlaşması, karbon dağılımında değişiklik, kavitasyon, azot asimilasyonunda azalma, iyon sitotoksisitesi ve hücre ölümü gibi süreçleri tetikleyerek bitki büyümesi ve veriminde ciddi bir azalmaya yol açmaktadır (Ashraf ve Harris, 2004; Munns ve Tester, 2008; Acosta-Motos, Ortuño, Bernal-Vicente, Diaz-Vivancos, Sanchez-Blanco ve Hernandez, 2017; Farooq, Gogoi, Hussain, Barthakur, Paul, Bharadwaj, ... ve Siddique, 2017; Arif, Singh, Siddiqui, Bajguz ve Hayat, 2020).

Bu nedenle, tuzlulukla mücadele etmek için yeni stratejiler geliştirilmektedir. Bu doğrultuda son yıllarda biyostimülanlar, bitkilerin stres koşullarındaki performansını destekleyen ve sürdürülebilir üretim sistemlerinde kullanılabilecek tamamlayıcı uygulamalar olarak öne çıkmaktadır. Bu çalışmada, biyostimülanların tuz stresinin yönetimindeki rolü güncel literatür doğrultusunda değerlendirilmiştir. Çalışma kapsamında; mikrobiyal biyostimülanlar (özellikle bitki gelişimini teşvik eden rizobakteriler-PGPR), alg ve bitki ekstraktları ile aminoasit/protein temelli doğal biyostimülanların bitkilerde oluşturduğu fizyolojik ve biyokimyasal yanıtlar incelenmiştir.

BİYOSTİMÜLANLARIN TUZ STRESİ ÜZERİNE ETKİLERİ

Bitki Esktraktları

Doğal bitki ekstraktlarının kullanımı, tuzluluğun olumsuz etkilerini hafifletmeye yönelik çevre dostu ve kimyasal gübrelere alternatif potansiyel bir stratejidir. Bitkisel biyostimülan kategorisinde değerlendirilen bu ekstraktlar, stres koşullarında bitki gelişimini ve performansını teşvik etmek amacıyla yaygın olarak kullanılmaktadır (Calvo, Nelson ve Kloepper, 2014; Drobek, Frąc ve Cybulska, 2019).

Bitki konsantreleri olan özütler; tohum, kök, gövde, yaprak, kabuk, çiçek gibi bitkinin herhangi bir kısmı kullanılarak hazırlanabilirler (Semida ve Rady, 2014; Lorenzo, Souza-Alonso, Guisande-Collazo ve Freitas, 2019; Nessim ve Kasim, 2019; Rady, Talaat, Abdelhamid, Shawky ve Desoky, 2019b; Zulfiqar, Casadesús, Brockman ve Munné-Bosch, 2020). Ekstrakt uygulamaları; yapraktan püskürtme ve/veya kök uygulaması şeklinde sıvı formda ya da granül, konsantre, toprağa eklenen çözeltiler veya tozlar gibi toprak düzenleyici formlarda gerçekleştirilebilir (Drobek, Frąc ve Cybulska, 2019). Vitaminler, karotenoidler, amino asitler, bitki hormonları, mineral besin maddeleri, fenolik bileşikler ve antioksidanlar gibi önemli fitokimyasalları içermeleri nedeniyle, bitki ekstraktlarının tuzluluk stresinin iyileştirilmesinde rol oynadığı belirtilmektedir (Abdel Latef, Abu Alhmad ve Ahmad, 2017). Tek başlarına veya karışım halinde kullanılan bu bileşiklerin tuzluluğa karşı etkili olduğunu gösteren çeşitli çalışmalar bulunmaktadır (Calvo, Nelson ve Kloepper, 2014; Iqbal, Umar, Khan ve Khan 2014; Bulgari, Cocetta, Trivellini, Vernieri ve Ferrante, 2015; Drobek, Frąc ve Cybulska, 2019; Shukla, Mantin, Adil, Bajpai, Critchley ve Prithiviraj, 2019; Zulfiqar, Casadesús, Brockman ve Munné-Bosch, 2020). Bununla birlikte, bitki ekstraktlarının etkisi genellikle konsantrasyona bağlıdır. Benzer şekilde, özüt elde etmek için kullanılan bitki kısmı ve bitkinin yaşı da bitki ekstraktlarının genel etkinliğini etkilemektedir.

Bitki ekstraktlarının (BE) dışsal (eksojen) uygulamasında temel amaç, hücresel homeostazın korunmasını destekleyerek bitkinin tuz stresine karşı sergilediği savunma mekanizmalarını ve yanıt düzeyini güçlendirmektir. Yapılan araştırmalar, BE uygulamalarının bitkilerdeki sinyal iletim mekanizmaları, birincil ve ikincil metabolik yolaklar ile diğer hayati fizyolojik süreçler üzerinde düzenleyici rol oynadığını ortaya koymuştur (Ahmad, Blasco ve Martos, 2022).

Bunun yanı sıra, morfolojik ve anatomik uyumlar da bitkilerin stres koşullarını yönetmesinde kritik öneme sahip mekanizmalardır. Tuz stresi altındaki bitkilerde BE kullanımı; bitki boyu, kök ve sürgün uzunluğu, kök ve sürgün yaş/kuru ağırlıkları, kök/sürgün oranı, yaprak sayısı, yaprak alanı, yaprak kalınlığı, yaprak bağıl su içeriği (RWC), bakla sayısı ve ağırlığı, tohum sayısı ve ağırlığı, tane verimi, biyolojik verim ile hasat indeksi gibi temel büyüme ve verim parametrelerinde belirgin iyileşmeler sağlamıştır (Habib, Ashraf, Ali ve Perveen, 2012; Rady, Mohamed, Abdalla ve Ahmed, 2015; Latif ve Mohamed, 2016; Merwad, 2020; Suryaman, Sunarya, Istarimila ve Fudholi, 2021). Büyüme ve verim bileşenlerindeki bu olumlu değişimlerin; artan strese tolerans kapasitesi, yedek madde ve fotosentetik pigment birikimindeki artış, gaz değişim oranlarının korunması ve hücresel iyonik kompartmantasyon sayesinde glikofitlerin (tuza duyarlı bitkiler) stres koşullarına daha iyi adaptasyon sağlamasından kaynaklandığı değerlendirilmektedir.

Diğer taraftan, hücresel düzeyde gerçekleşen bu tür adaptif değişimlerin sürdürülebilmesi için gerekli enerji ve substrat akışı besin maddeleri tarafından sağlanmaktadır. Ancak tuzluluk koşullarında bitkilerin besin elementi alımı büyük ölçüde kısıtlanmaktadır (Munns ve Tester, 2008; Zörb, Geilfus ve Dietz, 2019). Dışsal BE uygulamaları, tuz stresinin besin alımı üzerindeki bu baskılayıcı etkisini hafifletmede etkili bir yaklaşım sunmaktadır. Nitekim yürütülen çok sayıda çalışma, BE uygulamalarının tuz stresi altındaki bitkilerde başta N, P, K, Fe, Zn ve Mn olmak üzere makro ve mikro besin elementlerinin alımını ve asimilasyonunu önemli ölçüde artırdığını göstermektedir (Bulgari, Cocetta, Trivellini, Vernieri ve Ferrante, 2015; Rady, Desoky, Elrys ve Boghdady, 2019a; Merwad, 2020).

Mikrobiyal Biyostimülanlar

PGPR (bitki gelişimini teşvik eden rizobakteriler) ve AMF (arbusküler mikorizal mantarlar) gibi mikrobiyal biyostimülanların kullanımı; aşırı sıcaklıklar ve kuraklığın yanı sıra özellikle tuzluluk başta olmak üzere bitkilerin abiyotik stres faktörlerine karşı toleransını artırmada yenilikçi bir teknoloji olarak kabul edilmektedir. Bitki kökleri ile PGPR ve AMF arasındaki sinyal alışverişi de dahil olmak üzere bu yararlı mikroorganizmalar, çevresel strese tolerans hususundaki mekanizmalarda ve besin maddesi alımında (özellikle N ve P) kritik rol oynamaktadır (Backer, Rokem, Ilangumaran, Lamont, Praslickova, Ricci, ve Smith, 2018; Granada, Passaglia, De Souza ve Sperotto, 2018; Bitterlich, Rouphael, Graefe ve Franken, 2018). AMF ve ilişkili mikrobiyatanın işlevsel tamamlayıcılığı kapsamında; bitki gelişimini teşvik eden bakteriler (PGPB) ile mikoriza yardımcı bakterileri (MHB), AMF aktivitesini ve gelişimini destekleyerek hem optimum hem de sub-optimum stres koşulları altında ürün verimliliğini artırmaktadır (Turrini, Avio, Giovannetti ve Agnolucci, 2018). Tuzluluk koşullarında mikrobiyal biyostimülanların kullanımı da bitki toleransını artırmada etkili bir yaklaşım sunmaktadır.

Azot bağlama, oksin ve siderofor üretimi ile inorganik fosfat çözme yeteneğine sahip halotolerant (tuza toleranslı) PGPR ırklarının, yüksek tuz stresi altında aşılanan makarnalık buğday bitkilerinde çimlenme yüzdesi ile kök büyümesini artırarak agronomik performansı ve canlı kalma oranını belirgin şekilde iyileştirdiği saptanmıştır (Albdaiwi, Khyami-Horani, Ayad, Alananbeh ve Al-Sayaydeh, 2019). Bununla birlikte, yüksek tuzluluk koşullarında yetiştirilen marul (*Lactuca sativa* L.), biber (*Capsicum annuum* L.), nohut (*Cicer arietinum* L.) ve bakla (*Vicia faba* L.) bitkilerinde *Azospirillum brasilense* uygulamalarının tuz stresine karşı toleransı artırdığı ve pozitif agronomik sonuçlar sağladığı bildirilmiştir (Ruzzi ve Aroca, 2015; Hamaoui, Abbadi, Burdman, Rashid, Sarig ve Okon, 2001).
PGPR'ler, çeşitli tamamlayıcı mekanizmalar yoluyla iyon dengesinin yeniden sağlanmasında kritik bir rol oynar. Tuz stresi altında, PGPR aşılama işlemi kök dokularında Na^+ ve Cl^- birikimini azaltarak iyon toksisitesini hafifletir ve hücresel bütünlüğü korur (Carreiras, Caçador ve Duarte, 2022; Etesami ve Maheshwari 2018; Nadeem, Zahir, Naveed ve Nawaz, 2013). Eş zamanlı olarak, PGPR yapraklarda K^+ ve Ca^{2+} alımını ve birikimini artırarak, metabolik olarak aktif dokulara daha iyi seçici iyon taşınmasını ve besin iletimini yansıtabilir (Gao, Zhang, Zhang, Zhang, ZhengBorjigin ve Wang, 2022; Pan, Peng, Xue, You, Zhang, Wang ve Huang, 2019; Zhang, Tong, Wang ve Bie, 2024). Bu iyileştirmeler, hem köklerde hem de sürgünlerde artan K^+/Na^+ ve Ca_2^+/Na^+ oranları, daha iyi besin durumu ve gelişmiş fotosentetik performans ile yakından ilişkilidir ve sonuç olarak bitki büyümesini ve tuzluluk toleransını iyileştirmeye katkıda bulunur (Etesami ve Maheshwari 2018; Kumar, Singh, Gaurav, Srivastava ve Verma, 2020; Pan, Peng, Xue, You, Zhang, Wang ve Huang, 2019; Zhang, Tong, Wang ve Bie, 2024). PGPR'lerin ayrıca, yüksek afiniteli K^+ taşıyıcılarının ekspresyonunu etkilediği ve böylece tuzlu koşullar altında seçici K^+ alımını teşvik ettiği gösterilmiştir (Rojas-Tapias, Moreno-Galván, Pardo-Díaz, Obando, Rivera ve Bonilla, 2012). PGPR'ler, iyon seçiciliğini artırarak tuz stresi altındaki bitkilerde K^+/Na^+ homeostazının iyileştirilmesiyle ilişkilidir (Etesami ve Maheshwari 2018; Pan, Peng, Xue, You, Zhang, Wang ve Huang, 2019; Paul ve Lade 2014). Ek olarak, PGPR, besin alımını artırarak ve oksidatif stres etkilerini hafifleterek iyon dengesini dolaylı olarak destekler ve bu etki, AMF ile birlikte kullanıldığında daha da güçlendirilebilir (Zhang, Tong, Wang ve Bie, 2024).

Aminoasit/Protein Temelli Biyostimülanlar

Amino asitlerin biyostimülan olarak kullanımının stresli koşullar altında bitki büyümesi ve gelişimi üzerinde olumlu etkileri olduğunu göstermektedir (Peña Calzada, Olivera Viciedo, Habermann, Calero Hurtado, Lupino Gratão, De Mello Prado, ... ve Rodríguez, 2022; Mandal, Anand, López-Bucio, Kumar, Lal, Tiwari ve Dey, 2023; Matysiak, Kierzek, Siatkowski, Kowalska, Krawczyk ve Miziniak, 2020). Amino asitler, organik azot sağlayarak ve glutamin biyosentezinde önemli rol oynayan protein birimleri olarak bitki gelişiminde faydalı bir role sahiptir (Mandal, Anand, López-Bucio, Kumar, Lal, Tiwari ve Dey, 2023) ve bitki büyüme düzenleyicileri olarak da görev yaparlar (Sun, Shahrajabian, Kuang ve Wang, 2024). Tuzluluk koşullarında amino asitler iyon taşınımını düzenler, stoma açıklığını kontrol eder, enzim aktivasyonunu sağlar ve redoks homeostazının korunmasına yardımcı olur (Mandal, Anand, López-Bucio, Kumar, Lal, Tiwari ve Dey, 2023; Cheng, Tian ve Zhang, 2016). Örneğin glisin, bitki beslenmesinde yaygın olarak kullanılır ve çok çeşitli amino şelatlı gübreler üretir (Zargar Shooshtari, Souri, Hasandokht ve Jari, 2020). Arjinin, poliamin sentezinde ve molekül sinyallemesinde öncü bir maddedir ve en yüksek N/C oranına sahip en çok işlevli amino asitlerden biridir (Sun, Miao, Wang, Liu, Wang, Wang, ... ve Yang, 2023). Amino asitlerin uygulanması, tuz stresinin etkilerini hafifletmek için önemli bir araçtır çünkü protein sentezinde ve diğer hayati hücresel fonksiyonlarda bitki metabolitleri için gerekli moleküllerdir. Yapılan bir çalışmada; biyostimülan uygulanan biber bitkilerinde, bitki boyu, kuru madde, yaprak alanı ve yaprak sayısı gibi büyüme parametrelerinin yanı sıra meyve boyutu, sertlik, askorbik asit ve suda çözünür kuru madde (SÇKM) gibi kalite unsurlarında belirgin üstünlük göstermiştir. Biyostimülanın her iki dozu da klorofil seviyelerini daha yüksek tutarak (%15 artış), fotosentez performansını destekleyerek (%20 artış), yaprak su statüsünü ile meyve boyutu ve kalitesini iyileştirerek tuz stresinin olumsuz etkilerini hafifletmiştir. Bu olumlu etkilerin arkasında yatan biyokimyasal mekanizmaların, artan osmoregülasyon kapasitesi ve yükselen antioksidan aktivite olduğu belirlenmiştir. Sonuç olarak, biyostimülanın yapraktan uygulanması tuz stresi altındaki biber bitkilerinin toleransını artırmada etkili bir strateji olduğu bildirilmiştir (Silva, de Farias, Corrêa, de Lacerda, de Melo ve Oliveira, 2025).

SONUÇ

Tuzluluk; ozmotik hasar, iyon toksisitesi, hormonal dengesizlikler ve oksidatif hasara yol açarak küresel tarımsal sürdürülebilirliği tehdit eden en ciddi abiyotik stres faktörlerinden biri olmaya devam etmektedir. Mevcut literatürün bir sentezi; mikrobiyal inokülantlar (PGPR ve AMF gibi), alg/bitki ekstraktları ve amino asit/protein bazlı formülasyonları kapsayan biyostimülantların, ürünlerde tuz kaynaklı hasarı hafifletmek için umut verici ve çevre dostu bir strateji sunduğunu göstermektedir. Biyostimülantlar, toprağın fiziksel tuzluluk düzeyini değiştirmek yerine, bitki bünyesindeki temel fizyolojik ve biyokimyasal ağları düzenleyerek etki ederler. Biyostimülant uygulamaları; kök mimarisini geliştirir, yaprak bağıl su içeriğini (RWC) korur, fotosentetik pigmentleri muhafaza eder ve stoma iletkenliğini koruma altına alır; böylece tuzlu ortamlarda karbon asimilasyonunun ve genel biyokütle üretiminin sürdürülmesini sağlar. Mikrobiyal (örneğin PGPR) ve mikrobiyal olmayan biyostimülantlar, seçici iyon taşıma mekanizmalarını düzenleyerek toksik Na^+ ve Cl^- alımını sınırlar ve buna karşılık seçici K^+ve Ca_2^+ emilimini teşvik eder. Biyostimülantlar, ozmolitlerin (prolin ve çözünür şekerler gibi) endojen sentezini uyarır ve temel enzimatik antioksidanların (SOD, CAT, APX, GR) aktivitesini artırır. Bu biyokimyasal güçlendirme, reaktif oksijen türlerinin (ROS) birikimini hafifleterek malondialdehit (MDA) seviyelerini, hidrojen peroksit üretimini ve membran elektrolit sızıntısını önemli ölçüde azaltır. Çeşitli ürün türlerinde biyostimülant uygulamaları; verim bileşenleri, meyve sertliği, besin profili (örneğin askorbik asit içeriği) ve toplam çözünür katı madde değerlerinde ölçülebilir iyileşmeler sağlar. Sonuç olarak biyostimülantlar, toprak tuzluluğuna karşı tek başına çözüm sunan araçlar olarak değil; bitkilerin doğal stres tolerans mekanizmalarını destekleyen hayati ve bütünleştirici fizyolojik hazırlama (priming) araçları olarak değerlendirilmelidir.

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AKILLI SERA TEKNOLOJİLERİ İLE VERİM VE ÜRÜN KALİTESİNİN İYİLEŞTİRİLMESİNE YÖNELİK YAKLAŞIMLAR

APPROACHES TO IMPROVING YIELD AND PRODUCT QUALITY WITH SMART GREENHOUSE TECHNOLOGIES

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ÖZET
Örtüaltı yetiştiriciliğinde çevresel koşulların ve yetiştiricilik uygulamalarının hassas biçimde yönetilmesi, verim, kaynak kullanım etkinliği ve ürün kalitesinin iyileştirilmesi açısından önem taşımaktadır. Bu çalışmada, akıllı sera teknolojileri ile sera sebzelerinde verim ve ürün kalitesinin iyileştirilmesine yönelik güncel yaklaşımlar literatür doğrultusunda değerlendirilmiştir. Domates, hıyar ve tatlı biber yetiştiriciliğinde sulama, fertigasyon, su ve besin yönetimi, bitki gelişiminin izlenmesi ve çevresel koşulların düzenlenmesine yönelik uygulamaların verim ve kaynak kullanım etkinliğiyle ilişkili olduğu bildirilmektedir. Özellikle hıyar yetiştiriciliğinde su eksikliği, tuzluluk ve besin dengesizliklerinin yönetimi; domateste optimize edilmiş fertigasyon uygulamaları, tatlı biberde ise mikroklima ile ilişkili fizyolojik ve iyonik dengenin korunması, üretim performansının iyileştirilmesi açısından değerlendirilmektedir. Akıllı sera sistemlerinde sensörler, otomasyon ve kontrol sistemlerinin kullanılması, üretim süreçlerinin ve çevresel koşulların sürekli izlenmesine ve sera yönetiminin optimize edilmesine olanak sağlamaktadır. Akıllı teknolojilerin sera yönetiminde kullanılmasının kaynak verimliliği ve üretim süreçlerinin iyileştirilmesiyle ilişkili olduğu, ancak teknoloji kullanımının iklim koşulları, ekonomik koşullar ve seraların teknik özellikleriyle birlikte değerlendirilmesi gerektiği bildirilmektedir. Ürün kalitesi açısından ise hasat öncesi çevresel koşullar, kültürel uygulamalar, genetik materyal ve yetiştirme sistemlerinin kalite özellikleriyle ilişkili olduğu; sera sebzelerinde görsel özellikler, tekstür, besin bileşimi ve duyusal özelliklerin yetiştirme koşullarından etkilenebildiği belirtilmektedir. Bunun yanında otomasyon ve enerji yönetimi, sera üretim sistemlerinin verimliliği ve sürdürülebilirliği açısından önemli teknolojik yaklaşımlar arasında değerlendirilmektedir. Sonuç olarak literatür, akıllı sera teknolojilerinin çevresel koşulların, su ve besin yönetiminin ve üretim süreçlerinin daha hassas biçimde yönetilmesine katkı sağlayarak verim, ürün kalitesi, kaynak kullanım etkinliği ve sürdürülebilir sera üretiminin geliştirilmesinde önemli bir araç olduğunu göstermektedir.
Anahtar Kelimeler: Akıllı sera, sera sebzeciliği, verim, ürün kalitesi, sensör teknolojileri, otomasyon, sulama, fertigasyon.

ABSTRACT
In greenhouse cultivation, precise management of environmental conditions and cultivation practices is crucial for improving yield, resource use efficiency, and product quality. This study evaluates current approaches to improving yield and product quality in greenhouse vegetables using smart greenhouse technologies, based on the literature. It is reported that irrigation, fertigation, water and nutrient management, plant growth monitoring, and environmental condition regulation are related to yield and resource use efficiency in tomato, cucumber, and sweet pepper cultivation. Specifically, the management of water deficiency, salinity, and nutrient imbalances in cucumber cultivation; optimized fertigation practices in tomato cultivation, and the maintenance of physiological and ionic balance in relation to microclimate in sweet pepper cultivation are evaluated in terms of improving production performance. The use of sensors, automation, and control systems in smart greenhouse systems allows for the continuous monitoring of production processes and environmental conditions and the optimization of greenhouse management.

It is reported that the use of smart technologies in greenhouse management is associated with resource efficiency and improved production processes; however, technology use should be evaluated in conjunction with climatic and economic conditions and the technical characteristics of greenhouses. In terms of product quality, pre-harvest environmental conditions, cultural practices, genetic material, and cultivation systems are reported to be related to quality characteristics, while visual characteristics, texture, nutrient composition, and sensory characteristics of greenhouse vegetables can be affected by growing conditions. In addition, automation and energy management are considered important technological approaches for improving the efficiency and sustainability of greenhouse production systems. In conclusion, the literature shows that smart greenhouse technologies are important tools for improving yield, product quality, resource use efficiency, and sustainable greenhouse production by contributing to more precise management of environmental conditions, water and nutrients, and production processes.

Keywords: Smart greenhouses, greenhouse vegetable farming, yield, product quality, sensor technologies, automation, irrigation, fertigation.

GİRİŞ

Günümüzde, başta sanayileşme ve kentleşmenin neden olduğu iklim değişikliği ve bunun yol açtığı etkiler, doğal döngülere yönelik kapsamlı insan müdahalelerine sebebiyet vermiştir (Tao ve ark, 2021; Barati ve ark., 2026). Son yıllarda, nüfus artışı ile gıda, mal ve hizmetlere olan talebin yükselmesiyle ortaya çıkan ihtiyaçları karşılamak amacıyla doğal kaynakların ve yenilenemeyen enerji kaynaklarının sürdürülemez ve aşırı kullanımı, insanlığın temel zorluklarından biri haline gelmiştir (Tubiello ve ark., 2015; Fróna ve ark., 2019). Örneğin, dünya nüfusunun 2050 yılına kadar yaklaşık 10 milyara ulaşması beklenmekte olup, bu nüfusun gıda gereksinimini karşılamak için 2010 yılında üretilen toplam gıda miktarından yaklaşık %56 daha fazla gıda üretimi gerekecektir. İklim değişikliği; sıcaklık, yağış düzenleri ve diğer atmosferik koşullardaki uzun vadeli değişimleri ifade eder ve aşırı hava olaylarına, sellere, kuraklıklara ve orman yangınlarına yol açar (Pachauri ve ark., 2014; Dietz ve ark., 2026; Bolan ve ark., 2024). Bu sorun, yalnızca insan yaşamı için değil, aynı zamanda tüm gezegen için bir tehdit oluşturmaktadır. Bu değişimlerin en önemli etkilerinden biri, bitkisel ve hayvansal üretim dahil olmak üzere tarım sektörü üzerinde görülmüştür (Chandio ve ark., 2024). Örneğin; artan sıcaklıklar, değişen yağış düzenleri, aşırı hava olaylarının sıklığındaki artış, yükselen CO_2 emisyonları, büyüme mevsimlerindeki kaymalar, toprak bozulması ve su krizi gibi unsurlar tarımı etkileyebilecek temel iklim değişikliği faktörleridir (Bright ve ark., 2025; Qu ve ark., 2025; Barati ve ark., 2023; Manucharyan, 2025). Bu faktörler; ürünlerde strese yol açarak verim ve üretkenliği düşürebilir, toprak nemini azaltabilir veya toprak besin maddelerini yıkayıp götürebilir, zararlıların ve hastalıkların yayılma alanını ve yaşam döngüsünü genişletebilir, pestisit kullanımını ve buna bağlı çevresel riskleri artırabilir. Elbette, tarım ile iklim koşulları arasında çift yönlü bir ilişki olduğu göz ardı edilmemelidir; yani bu iki unsur birbirini etkiler ve birbirinden etkilenebilir (Bright ve ark., 2025). Dolayısıyla, her birinin sürdürülebilir yönetimi, diğerinin de sürdürülebilirliğine katkı sağlayabilir. Tarımın gıda güvenliğini sağlamadaki kritik rolü göz önüne alındığında, iklim değişikliği bu güvenlik için ciddi bir tehdit oluşturmaktadır (Pawlak ve Kołodziejczak, 2020). Buna bir yanıt olarak insanlık, iklimsel parametrelerden daha az etkilenen seralar gibi kontrollü ortamlarda ürün yetiştirme gibi yenilikçi tarım yöntemlerine yönelmiştir (Barati ve ark., 2025). Sera tarımının geliştirilmesi gıda güvenliğinin sağlanmasına ve tarımsal üretimle ilişkili risklerin azaltılmasına katkıda bulunabilse de, seraların yetersiz ve geleneksel yöntemlerle yönetilmesi zararlı çevresel etkilere yol açabilir; bu durum da beraberinde ekonomik ve sosyal sonuçlar doğurabilir. Bu nedenle, geleneksel sera yönetim sisteminin iyileştirilmesi ve seralarda kullanılan teknolojilerin güncellenmesi bir zorunluluktur. Bu bağlamda; Nesnelerin İnterneti (IoT), sensörler, dronlar ve diğer akıllı teknolojilerin geliştirilmesine paralel olarak, sera işletmecileri de yönetim süreçlerini optimize etmek ve üretim verimliliğini artırmak amacıyla bu teknolojileri benimsemeye başlamıştır (Barati ve ark., 2026). Bu bağlamda, akıllı tarım, özellikle akıllı sensörler ve veri analitiği gibi gelişmiş teknolojileri kullanan ve çiftçilerin gerçek zamanlı bilgilere dayalı olarak bilinçli kararlar almalarını sağlayan yenilikçi bir yöntem olarak öne çıkmaktadır (Cammarano ve ark., 2023). Akıllı sensörleri kullanarak mahsullerin, toprağın ve çevresel koşulların belirli yönlerini izlemek ve analiz etmek suretiyle, hassas tarım, çiftçilere girdileri ve müdahaleleri, bireysel bitkilerin veya tarlanın belirli alanlarının ihtiyaçlarına tam olarak uyarlama olanağı sağlar.

Hassas tarımın potansiyel faydaları çok yönlüdür. Birincisi, kaynak israfını azaltırken mahsul verimini ve genel verimliliği önemli ölçüde artırma vaadi sunar (Akaka ve ark., 2023). İkincisi, kaynakları daha verimli kullanarak ve çevresel etkileri en aza indirerek, hassas tarım sürdürülebilir ve sorumlu tarım uygulamalarına katkıda bulunur (Zaman, 2023). Üçüncüsü, değişen çevresel koşulları öngörme ve bunlara yanıt verme yeteneği, iklim değişkenliğine karşı direnci artırarak, sektörün küresel iklim değişikliğinin ortaya koyduğu zorluklara dayanma yeteneğini geliştirir. Modern tarımda akıllı sensör teknolojilerinin benimsenmesi, gıda üretme şeklimizde devrim yaratmada ve tarım sektörünün bugün karşılaştığı sayısız zorluğun üstesinden gelmede büyük önem taşımaktadır (Shanmugasundaram ve ark., 2023). Bu gelişmiş sensörler, en son teknolojilerle donatılmış ve modern teknolojilerle entegre edilmiş olup, daha sürdürülebilir, verimli ve dayanıklı tarım uygulamalarına katkıda bulunan geniş bir yelpazede fayda sunmaktadır. Ancak, söz konusu teknolojilerin sera yetiştiriciliğindeki başarısı; ürün grubuna, yetiştiricilik ortamına ve çevre kontrol stratejilerine bağlı olarak değişkenlik göstermektedir. Bu doğrultuda çalışma; akıllı sera teknolojilerinin verim, ürün kalitesi, su-besin yönetimi ve kaynak kullanım etkinliği üzerindeki etkilerini güncel literatür ışığında değerlendirmeyi ve sürdürülebilir örtüaltı üretimine yönelik bütüncül bir perspektif sunmayı amaçlamaktadır.

Akıllı Sera Teknolojilerinin Verim, Ürün Kalitesi, Su-Besin Yönetimi Ve Kaynak Kullanım Etkinliği Üzerindeki Etkilerine Ait Literatür Değerlendirmesi

Akıllı sera işletmeciliğinde iklimlendirme (ısıtma, soğutma), yapay aydınlatma ve fertigasyon süreçleri yüksek miktarda enerji gerektirmekte; enerji maliyetleri toplam sera işletme giderlerinin yaklaşık %25'ini oluşturmaktadır (Iddio ve ark., 2020). Geleneksel Oransal-İntegral-Türev (PID) kontrolörlerin ani dış ortam değişimlerine ve karmaşık non-lineer sera dinamiğine uyum sağlamadaki yetersizlikleri sebebiyle; Parçacık Sürü Optimizasyonu (PSO), Evrimsel Algoritmalar (EA) ve Karınca Kolonisi Optimizasyonu (ACOA) gibi biyolojik esinli (bio-inspired) yapay zeka algoritmaları öne çıkmaktadır (Zhang ve ark., 2022; Iddio ve ark., 2020; Jia ve ark., 2021). Bu algoritmalar; fotovoltaik (PV) paneller ve dinamik elektrik fiyatlandırma sistemleriyle entegre çalışarak seranın enerji maliyetlerini belirgin şekilde düşürmekte, kestirimci ışık kontrol modelleri (PBM) sayesinde yapay aydınlatma enerji giderlerinde %14 ile %33,85 arasında tasarruf sağlamaktadır.

Hassas sulama ve fertigasyon yönetiminin sera hıyar yetiştiriciliğindeki etkilerini inceleyen araştırmalar; yapay zeka destekli sulama ve besleme sistemlerinin su ve azot kullanım etkinliğini belirgin şekilde artırdığını göstermektedir. Örneğin, Çin'in Yangling bölgesinde sera hıyarında yapay zeka tabanlı sulama uygulamalarıyla verimde %17,5'lik bir artış sağlanırken, uygulanan azotun parsiyel faktör verimliliği %29 oranında yükseltilmiştir (Cui ve ark., 2020). Bu durum, AI destekli hassas sulama ve fertigasyonun geleneksel damla sulama ve manuel gübrelemeye kıyasla hem su kaynaklarını koruduğunu hem de ekonomik getiriyi artırdığını doğrulamaktadır.

Sera yetiştiriciliğinde akıllı karar destek sistemleri (DSS) ve değişken oranlı uygulama (VAR) teknolojileri, zararlı ve hastalık popülasyonlarını gerçek zamanlı izleyerek pestisit kullanımını önemli ölçüde azaltmaktadır. Bilgisayarlı algoritmalar ve nokta atışı püskürtme sistemleri sayesinde pestisit dozajlarında %33 ile %78 arasında tasarruf sağlanabildiği rapor edilmiştir (Facchinetti ve ark., 2021; Claver, 2020). Bu durum, taze sebze üretiminde kimyasal kalıntı riskini en aza indirerek hem ürün kalitesine hem de insan sağlığına doğrudan katkı sunmaktadır.

Sera domates ve biber yetiştiriciliğinde robotik sistemler ve yapay zeka algoritmaları; hassas meyvelerin hasadı, renk, boyut ve şekil parametrelerine göre sınıflandırılması ve hastalık tespiti gibi süreçlerde yaygınlaşmaktadır (Kootstra ve ark., 2021; Lee ve ark., 2020). Yumuşak kavrayıcı (soft robotic griper) teknolojileri hassas sebze dokularına zarar vermeden hasadı mümkün kılarken; Recurrent Neural Network (RNN), LSTM ve CNN-SVM gibi hibrit yapay zeka modelleri, sera içi mikroklima değişimlerini (sıcaklık, oransal nem, evapotranspirasyon) %90'ın üzerinde doğrulukla tahmin ederek fertigasyon ve iklimlendirme kontrolünü optimize etmektedir (Proietti ve ark., 2021).

Sera içi çevresel koşulların izlenmesinde Kablosuz Sensör Ağları (WSN) ve eyleyicilerle desteklenmiş Kablosuz Sensör ve Eyleyici Ağları (WSAN) öne çıkmaktadır. Örneğin, HortiMED-AI destekli Karar Destek Sistemleri (DSS); sensörler, çok katmanlı hiyerarşik kontrol mimarisi, IoT ve makine öğrenimi tekniklerini birleştirerek sera ısıtması, havalandırma ve fertigasyonu düşük maliyetle otomatikleştirmekte; bitki gelişimi ve besin yönetimine dair uzman tavsiyeleri sunabilmektedir (Otazua, 2022).

Sera içi oransal nemin yetersiz yönetimi; gün doğumu, gün batımı ve soğuk-bulutlu günlerde su moleküllerinin yoğuşmasına yol açarak külleme (powdery mildew) ve kurşuni küf (*Botrytis cinerea*) gibi fungal etmenlerin yayılmasına zemin hazırlamaktadır. Bu patojenler, yaprak yüzeyinde konidi ve konidiyoforlar oluşturarak klorofil sentezini kısıtlamakta ve doğrudan verim kayıplarına neden olmaktadır. Yapay zeka tabanlı iklimlendirme ve hassas sulama otomasyonu, nem dengesini proactive (önleyici) olarak düzenleyerek fungal hastalık riskini azaltmaktadır. Ayrıca, hiperspektral görüntüleme, yapay zeka ve LSTM derin öğrenme ağları kullanılarak yapraklardaki klorofil oluşumunun (SPAD değerleri) ve hastalık şiddetinin erken evrede tespiti mümkün kılınmaktadır (Liu ve ark., 2022; Abdulridha ve ark., 2020)

Geleneksel pestisit kullanımına alternatif olarak geliştirilen süksinik asit vb. biyostimulant formülasyonları ile biyolojik mücadele ajanlarının entegrasyonu, entegre zararlı yönetimi (IPM) açısından kritik öneme sahiptir (Homayoonzadeh ve ark., 2022). Özellikle tatlı biber yetiştiriciliğinde; beyazsinek ve çiçek tripslerine (*Frankliniella occidentalis*) karşı uygulanan biyolojik ve biyostimulant odaklı yönetim stratejilerinin, kimyasal ajanlara kıyasla ürün veriminde %35'e varan bir artış sağladığı belirlenmiştir (El Arnaouty ve ark., 2020). Bununla birlikte, biyolojik ajanların etkinliğinin mevsimsel koşullara ve popülasyon yoğunluğuna bağlı olarak değişebildiği göz önünde bulundurulmalıdır. Sera yetiştiriciliğinde yoğun ve aralıksız kimyasal kullanımı, zararlılarda yüksek düzeyde pestisit direncine yol açmaktadır. Özellikle Türkiye'deki örtüaltı üretim alanlarında kırmızıörümceğin (*Tetranychus urticae*) Bifenazate, Abamectin, Bifenthrin ve Hexythiazox aktif maddelerine karşı yüksek direnç geliştirdiği ve arrhenotokous çoğalma yeteneği sebebiyle popülasyon patlamalarına yol açtığı rapor edilmiştir (Kirisik ve Dagli, 2021; Solmaz ve ark., 2020; Alpkent ve ark., 2020). Bu durum, Avrupa ve Türkiye örtüaltı yetiştiriciliğinde ekonomik kayıpları artırmaktadır. Bu kimyasal kısıtlamaları aşmak için, IoT ve bulut tabanlı CNN/görüntü işleme sistemleri ile zararlı popülasyonlarının (kırmızıörümcek, trips, beyazsinek) erken evrede tespiti (%90 üzeri başarı oranıyla) ve nokta atışı uygulama yapılması stratejik bir zorunluluk haline gelmiştir (Karar ve ark., 2021; Rustia ve ark., 2022).

SONUÇ

Bu literatür değerlendirmesi, akıllı sera teknolojilerinin ve yapay zeka uygulamalarının örtüaltı sebze yetiştiriciliğinde verim, ürün kalitesi, su-besin yönetimi ve kaynak kullanım etkinliği üzerinde somut katkılar sunduğunu göstermektedir. Yapay zeka destekli sulama, fertigasyon ve kestirimci iklimlendirme sistemleri; sera hıyar ve domates üreticiliğinde su ve azot kullanım verimliliğini artırarak %17,5'e varan verim artışları sağlamakta, biyolojik esinli algoritmalar ise enerji maliyetlerini %30'a varan oranlarda düşürmektedir. Derin öğrenme, görüntü işleme ve hiperspektral izleme teknolojileri; külleme ve kurşuni küf gibi fungal patojenler ile trips, beyazsinek ve kırmızıörümcek popülasyonlarını %90'ın üzerinde doğrulukla erken safhada tespit edebilmektedir. Değişken oranlı nokta atışı ilaçlama ve biyostimulant entegrasyonu sayesinde pestisit kullanımı %78'e varan oranlarda azalmakta, bu durum Türkiye seralarında yaygınlaşan akarisit direncini kırmaya yardımcı olurken ürünlerdeki kimyasal kalıntı riskini de en aza indirmektedir. Yüksek ilk kurulum maliyetleri ve donanımsal sensör kısıtları devam etmekle birlikte; düşük maliyetli IoT platformları, kapasitif sensörler ve bölgesel şartlara uyumlu hibrit algoritmaların yaygınlaşması, sürdürülebilir ve tam otomasyonlu örtüaltı üretim için stratejik bir atılımdır.

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PRUNUS SPECIES: WORLD DISTRIBUTION, IMPORTANCE AND PHYTOCHEMICAL COMPOSITION

PRUNUS TÜRLERİ: DÜNYA GENELİNDE DAĞILIMI, ÖNEMİ VE FİTOKİMYASAL BİLEŞİMİ

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ABSTRACT
Widely distributed across the globe, the *Prunus* species includes both pure species and hybrids. Most *Prunus* species originated in eastern Asia, central Asia, and the Mediterranean region. Commercially produced peach and nectarine (*P. persica* L.), European plum (*P. domestica* L.), Japanese plum (*P. salicina* Lindl.), sour cherry (*P. cerasus* L.), sweet cherry (*P. avium* L.), almond (*P. dulcis* Miller), and apricot (*P. armeniaca* L.) species inhabit areas between 30 and 45° north and south latitudes. One of the best distinguishing features of *Prunus* species is their hard, single-seeded fruits, hence also called stone fruits. The edible mesocarp, which supports a strong diet, is highly productive and contains many phytochemicals important for human health. They also hold a very important position within the Rosaceae family in terms of their richness of wild related species. In particular, its use as a rootstock each other distinguishes it from other genera of the species. While cultivation preserves internationally recognized standard cultivars with large, attractive fruits and high yield capacity, wild relative species and local varieties are primarily preserved due to their resistance to biotic and abiotic stress.
Keywords: Prunus, dissemination, taxonomy, rootstock use

ÖZET
Dünya genelinde yaygın olarak bulunan Prunus cinsi, hem saf türleri hem de melezleri içerir. Çoğu Prunus türü Doğu Asya, Orta Asya ve Akdeniz bölgesinde ortaya çıkmıştır. Ticari olarak üretilen şeftali ve nektarin (*P. persica* L.), Avrupa eriği (*P. domestica* L.), Japon eriği (*P. salicina* Lindl.), vişne (*P. cerasus* L.), kiraz (*P. avium* L.), badem (*P. dulcis* Miller) ve kayısı (*P. armeniaca* L.) türleri, 30 ile 45° Kuzey ve Güney enlemleri arasındaki bölgelerde yayılım gösterir. Prunus türlerinin en belirgin özelliklerinden biri, sert, tek çekirdekli meyveleridir; bu nedenle onlara taş çekirdekli meyveler de denir. Güçlü bir diyeti destekleyen yenilebilir mezokarp, oldukça verimlidir ve insan sağlığı için önemli birçok fitokimyasal içerir. Ayrıca, yabani akraba türlerinin zenginliği açısından Rosaceae familyası içinde çok önemli bir konuma sahiptirler. Özellikle, birbirlerine anaç olarak kullanımı, cinsi diğer cinslerinden ayıran bir özelliktir. Yetiştiriciliği, iri, çekici meyvelere ve yüksek verim kapasitesine sahip uluslararası kabul görmüş standart çeşitlerle yapılırken, yabani akraba türleri ve yerel çeşitler öncelikle biyotik ve abiyotik strese karşı dirençleri nedeniyle önemini korumaktadır.
Anahtar Kelimeler: Prunus, yayılım, taksonomi, anaç kullanımı

INTRODUCTION

The genus Prunus, within the subfamily Prunoidea of the Rosaceae family, is highly diverse and represented by over 500 species on all continents except Antarctica in the world. Apricot, plum, cherries (sweet and sour cherry), almond, peach-nectarine, and almond are the main species, and it also includes numerous closely related wild species. The species belongs to Prunus, native to northern temperate regions. Many members of the genus are widely cultivated for their valuable fruits and for ornamental purposes. Prunus fruits are stone fruits.

While the fleshy mesocarp surrounding the endocarp is edible, the endocarp itself forms a hard, inedible shell called the pyrena ("stone" or "pit"). This shell surrounds the seed (or "kernel"), which is edible in many species (like almonds) but poisonous in others (like some apricots). Besides being eaten, most Prunus fruits are also widely used in processing, such as making jam, canning, drying, and roasting the seeds (Dosba and Zanetto, 2004). They are generally found in both deciduous and evergreen tree or shrub forms (Rodrigues-Robles et al., 2024).

The important species within the genus Prunus are of great economic value and many of these species hold significant horticultural values, with several being cultivated for their edible seeds and fruits (Służały et al., 2026).

These include popular species with diploid characteristics such as peach, apricot, sweet cherry, Japanese plum, and almond as well as tetraploid species such as sour cherry, and hexaploid European plum (Dosba and Zanetto, 2004).

Different species within the genus Prunus play crucial ecosystem roles worldwide. They provide shelter, food, and habitat for numerous pollinating insects, birds, and small mammals in their respective areas. Wild related species within the Prunus genus, due to their high adaptability, can adapt to different climates and soils, playing significant roles in food security and sustainability. Their early and abundant flowering makes them among the first sources of spring nectar, playing a vital role in the life cycle of pollinators. These species also contribute significantly to improving air quality, reducing soil erosion, and increasing the resilience of local ecosystems in their regions and areas. All Prunus species, trees and shrubs are supporting climate resilience and ecological diversity (Dosba and Zanetto, 2004).

Most of species are valued for their fruits has diverse pharmacological properties and are incorporated into therapeutic formulations in systems such as Unani, Traditional Chinese Medicine (TCM), Ayurveda, and Iranian Traditional Medicine. Across these systems, different parts of Prunus plants, including fruits, are employed in the treatment of various ailments, ranging from respiratory and gastrointestinal disorders to neurological and hepatic conditions (Służały et al., 2026).

Distribution on the world

Prunus, the most common genus within the Rosaceae family, is cultivated and densely represented in the wild in the form of shrubs or trees on all continents except Antarctica. Distribution on the world is shown in Figure 1 (Martin-Gomez et al., 2017). When we look at the world in general, it is seen that many Prunus species are more common in semi-arid climate zones. However, species are distributed in many different climate zones around the world. In terms of taxonomy, the genus is complex due to polymorphism and the species' broad ecological tolerance and the existence of a large number of cultivars. Most of the wild relatives which accepted as native species thrive across the temperate regions of North America, Eurasia and North Africa, with an especially high concentration and origin point in Eastern Asia (Donmez et al., 2000).

The Prunus genus, spread from east to west occurred primarily in waves via ancient trade networks such as the Silk Road. Later, European colonialism and modern agricultural distribution led to the global spread of these species (Martin-Gomez et al., 2017).

Among species, China is the centre of origin for peach and was domesticated there 4000-5000 years ago. The centre of origin of plum is extended from Asia, Europe to America for different biotypes/landraces. Centres of origin for major plum species can be broadly designated as China for Japanese plum (*Prunus salicina* Lindl.), southern Europe or western Asia for European plums (*Prunus domestica* L.), North America for American plum (*Prunus americana* Marsh.), western Asia or Europe for Damson plum (*Prunus insititia* L.), western and central Asia as well as Europe for cherry plum (*P. ceracifera* Ehrh.).

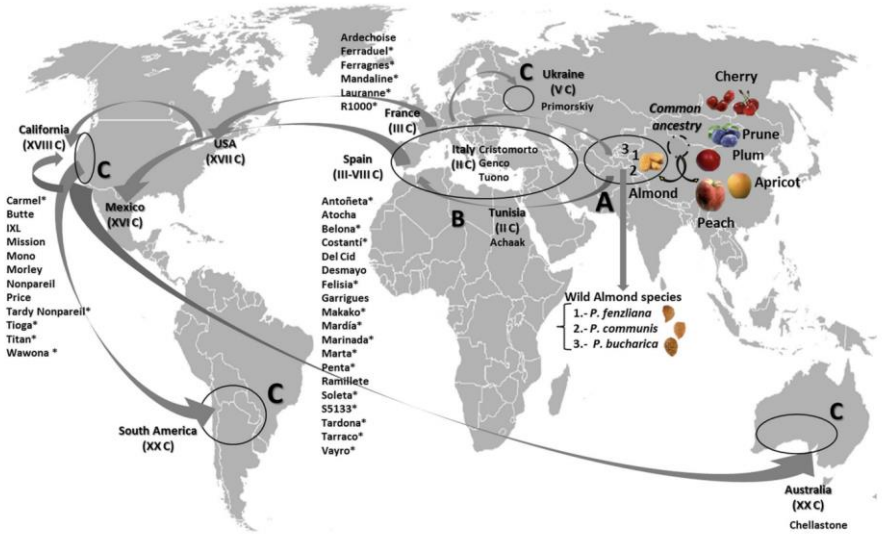


Fig. 1 Location of the origin of the most cultivated *Prunus* species together with the origin of some relative wild almond species, and dissemination of almond cultivation from the center of origin (*A*), to the diversification (*B*) and culture (*C*) areas. The century of introduction of the cultivated almond species is indicated between parenthesis. Most important almond cultivars in the production areas included in this review are also listed, those released from breeding programs are indicated by an *asterisk*

Prunus armeniaca L., the cultivated and wild apricot is native to Asia and Caucasus including north and north eastern China. Almond (*P. dulcis* Miller) originated in the central to south western Asia. Most of the cherry species are indigenous to Europe and Asia. Sweet (*Prunus avium* L.) and sour (*P. cerasus* L.) cherries are native to Near East centre which includes Asia Minor, Iran, Iraq and Syria (Faust et al., 1998; 1999; Das et al., 2011).

Major and minor species and hybrids

The major Prunus species are diploid peach (*Prunus persica*), apricot (*Prunus armeniaca*), sweet cherry (*Prunus avium*), Japanese plum (*Prunus salicina*), almond (*Prunus dulcis*), as well as tetraploid species such as sour cherry (*Prunus cerasus*) and hexaploid European plum (*Prunus domestica* L.). *Prunus mahaleb* and *Prunus laurocerasus* could be classified as major species within Prunus (Dosba and Zanetto, 2004) (Table 1, Figure 2).

The genus also includes many wild relatives as minor group (Table 2). Being a temperate crop, almost all the varieties of major Prunus can be grown successfully in the temperate regions of the world.

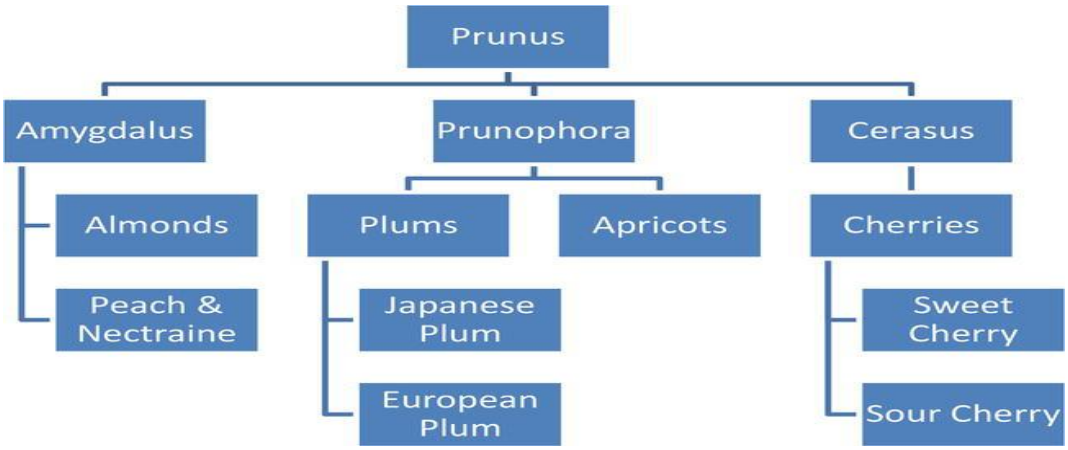


Figure 2. Botanical classification of Prunus genera

Table 1. Major species of Prunus and their wild relatives

Major Prunus species	**Turkish name**	**Yakın akraba türler**
Prunus armeniaca	Kayısı	*Prunus mume* (Japon kayısısı), *Prunus sibirica* (Sibirya kayısısı), *Prunus mandshurica* (Mançurya kayısısı), *Prunus brigantina* (Briançon kayısısı), *Prunus dasycarpa* (Mor kayısı)
Prunus domestica	Erik	*Prunus cerasifera* (Kiraz eriği), *Prunus salicina* (Japon eriği), *Prunus spinosa* (Çakal eriği), *Prunus insititia* (Damson eriği), *Prunus maritima* (Sahil eriği), *Prunus subcordata* (Oregon eriği), *Prunus nigra* (Kanada eriği), *Prunus mexicana* (Meksika eriği), *Prunus americana* (Amerikan eriği), *Prunus simonii* (Simon eriği), *Prunus mansoniana* (Munson eriği), *Prunus angustifolia* (Kum eriği)
Prunus avium	Kiraz	*Prunus maackii* (Amur kirazı), *Prunus padus* (Kuş kirazı), *Prunus africana* (Afrika kirazı), *Prunus cerasoides* (Himalaya kirazı), *Prunus fruticose* (Step kirazı), *Prunus incisa* (Fiji kirazı), *Prunus grayana* (Japon kuş kirazı), *Prunus japonica* (Japon kirazı), *Prunus serotina* (Kara kiraz), *Prunus tomentosa* (Tüylü kiraz)
Prunus dulcis	Badem	*Prunus lycioides, Prunus eburnea, Prunus fenzliana, Prunus carduchorum, Prunus orientalis, Prunus kotschyi, Prunus trichamygdalus, Prunus pabotti, Prunus urumiensis, Prunus korschinskii, Prunus bucharica, Prunus kuramica, Prunus spinosissima, Prunus webbii, Prunus pedunculate, Prunus turcomanica*
Prunus laurocerasus	Karayemiş	*Prunus insitanica* (Portekiz karayemişi), *Prunus occidentalis* (Batı kiraz karayemişi), *Prunus caroliniana* (Karolina karayemişi), *Prunus pleuradenia* (Antiller karayemişi)
Prunus cerasus	Vişne	
Prunus persica	Şeftali	
Prunus mahaleb	Mahlep	

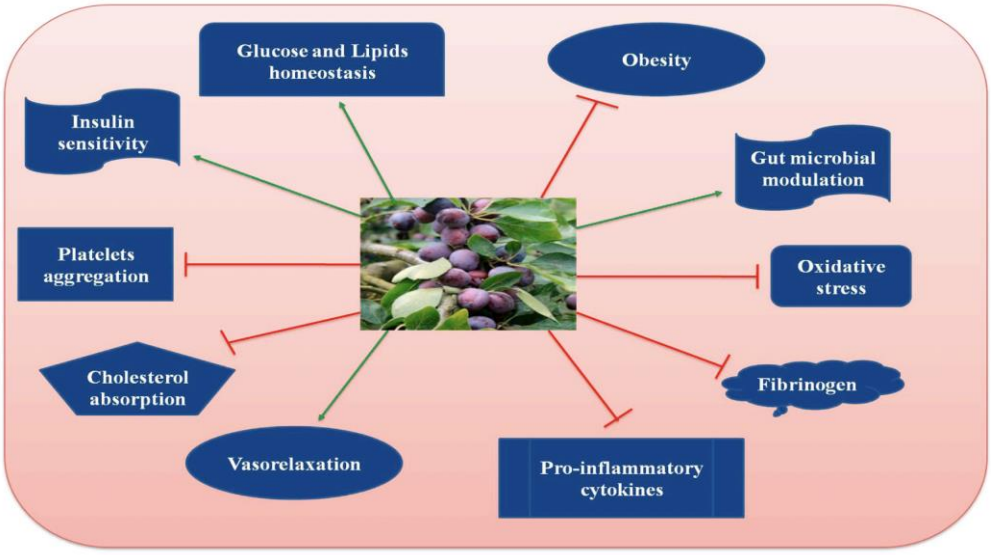
Table 2. Minor species of Prunus and hybrids between species

Minor Prunus species	**Turkish name**	**Minor Prunus species**	**Turkish name**
Prunus minutiflora	Teksas bademi	*Prunus incisa*	Fuji kirazı
Prunus murrayana	Murraya eriği	*Prunus japonica*	Japon kirazı
Prunus myrtifolia	Batı Hint Adaları Kirazı	*Prunus pensylvanica*	Kuş kirazı
Prunus alabamensis	Alabama kirazı	*Prunus prostrata*	Dağ kirazı
Prunus andersonii	Çöl şeftalisi	*Prunus pumula*	Kum kirazı
Prunus emarginata	Acı kiraz	*Prunus rivularis*	Dere eriği
Prunus fasciculata	Çöl bademi	*Prunus serrulate*	Süs kirazı
Prunus fremontii	Çöl kayısısı	*Prunus subhirtella*	Bahar kirazı

Prunus geniculate	Fırça eriği	*Prunus tenella*	Bodur Rus bademi
Prunus glandulosa	Bodur badem	*Prunus texana*	Teksas badem kirazı
Prunus gracilis	Ekşi erik	*Prunus triloba*	Çiçekli erik
Prunus havardii	Yabani badem	*Prunus umbellata*	Düz ağaç eriği
Prunus hortulana	Hortulan eriği	*Prunus virginiana*	Acı erik
Prunus ilicifolia	Kutsal yapraklı kiraz		

Phytochemical composition and human health effects

Prunus fruits contain bioactive compounds such as polyphenols, which make them potential alternative therapeutic agents for a number of chronic disorders including dysregulated metabolic conditions and they are effective for insulin sensitivity, glucose and lipids homeostasis, obesity, gut microbial modulation, oxidative stress, fibrinogen, pro-inflammatory cytokines, vasorelaxation, cholesterol absorption and platelets aggregation (Figure 3).



Figures 3. Benefits of Prunus consumption in metabolic syndrome.

Prunus species can target multiple targets which may protects against insulin resistance, visceral obesity, dysregulated metabolism of glucose and lipids, pro-thrombotic and hypercoagulable state and hypertension (Ullah et al., 2020).

Fruits of the genus *Prunus* (such as plums, cherries, and peaches) contain diverse phenolic profiles, dominated by hydroxycinnamic acids, anthocyanins, and flavonols. Different fruit species within the Prunus genus are notable for their varying fruit colors. This richness of color in Prunus species stems from anthocyanins, which are of great importance for human health. Anthocyanins are significant sources of valuable bioactive compounds (Popovic et al., 2021). Anthocyanidins and anthocyanins are antioxidant compounds that function to prevent or inhibit oxidative stress through hydrogen donation or single-electron transfer. Anthocyanin-rich different Prunus fruits such as sour cherry etc. have demonstrated promising potential as antidiabetic agents, owing to their ability to modulate key metabolic enzymes and improve glycemic control in both *in vitro* and *in vivo* models (Dodier et al., 2021). On the other hand, another importance of Prunus fruits is cancer prevention effects. Anticancer potential of Prunus fruits was reported by Omran et al. (2025) due to high phytochemical content. Anthocyanin-rich Prunus fruits showed significant antibacterial properties, effectively inhibiting the proliferation of multiple bacterial strains (Jeyaraj et al., 2021).

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HAWTHORN: IMPORTANCE AND RICHNESS IN TURKIYE

ALIÇ: TÜRKİYE'DEKİ ÖNEMİ VE ZENGİNLİĞİ

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,ABSTRACT
Serving as a bridge between east and west, Turkiye, with its relatively small geography, exhibits immense climatic, soil, and plant diversity, providing a natural habitat for many cultivated plant species, especially wild relative species. One of the most important horticulture species that stands out, and is perhaps the most prominent, in the Turkish flora is the hawthorn. Hawthorn (*Crataegus* spp) is an important wild edible fruit species that attracts attention due to its high nutritional value, ecosystem usefulness, and pharmacological potential. Possessing very valuable properties, hawthorn fruits have a wide range of uses as the functional food and in pharmaceutical industries, and this use is increasing year by year. Hawthorn species, which grow naturally in subtropical, cold, and warm temperate zones in the Turkish flora, exhibit a wide variety in nature. Hawthorn species are particularly resistant to harsh environmental conditions due to their strong root structure and secondary metabolite substance production. This study examines the importance and richness of Türkiye's hawthorn genetic resources in all its aspects.
Keywords: Wild fruits, hawthorn, morphological diversity, distribution

ÖZET
Doğu ve Batı arasında bir köprü görevi gören Türkiye, nispeten küçük coğrafyasıyla muazzam bir iklim, toprak ve bitki çeşitliliği sergileyerek, özellikle yabani akraba türleri olmak üzere birçok kültür bitkisi türü için doğal bir yaşam alanı sağlamaktadır. Türk florasında öne çıkan ve belki de en belirgin olan en önemli bahçe bitkisi türlerinden biri de alıçtır. Alıç (Crataegus spp), yüksek besin değeri, ekosistemdeki faydası ve farmakolojik potansiyeli nedeniyle dikkat çeken önemli bir yabani yenilebilir meyve türüdür. Çok değerli özelliklere sahip olan alıç meyveleri, fonksiyonel gıda ve ilaç endüstrisinde geniş bir kullanım alanına sahiptir ve bu kullanım her geçen yıl artmaktadır. Türkiye florasında subtropikal, soğuk ve ılıman bölgelerde doğal olarak yetişen alıç türleri, doğada geniş bir çeşitlilik göstermektedir. Alıç türleri, güçlü kök yapısı ve ikincil metabolit madde üretimi nedeniyle özellikle zorlu çevre koşullarına dayanıklıdır. Bu çalışma, Türkiye'nin alıç genetik kaynaklarının önemini ve zenginliğini tüm yönleriyle incelemektedir.
Anahtar kelimeler: Yabani meyveler, alıç, morfolojik çeşitlilik, dağılım

INTRODUCTION

Situated at the crossroads of important genetic centers and transitioning between the continents of Asia and Europe, Turkiye has historically known home to many great civilizations (Hittites, Seljuks, Ottomans), each of which made significant contributions to the plant diversity of these lands. Since the earliest times, the people of Anatolia have shown a great interest in wild edible fruits, and have achieved great successes for humanity in terms of traditional medicine practices based on these plants. This culture, gained through the traditional use of plants in human health, has been preserved remarkably well up to day (Ercisli, 2004; Altintas, 2022).

Hawthorn, belonging to the Rosaceae family and included in the soft-seeded fruit group in terms of horticulture classification based on fruit properties, is located within the genus Crataegus. This genus is a highly polymorphic and represented by approximately 200 taxa naturally grown on different continents worldwide (Yang and Liu, 2012) (Figure 1).

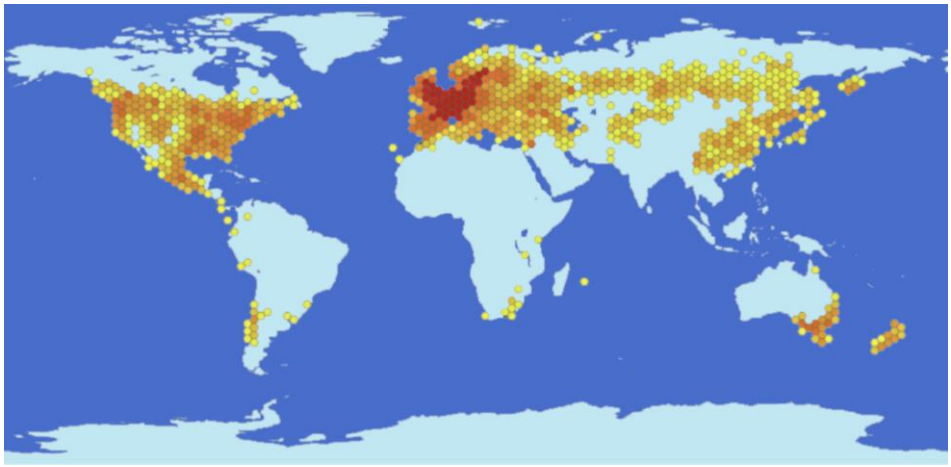


Figure 1. Distribution of hawthorn in the world (https://www.gbif.org/species/3013395).

Light to dark color changes indicate intensity

Among the species, *Crataegus pinnatifida* is the commonly distributed in China and Asia, and the *C. monogyna* and *C. laevigata* are mainly distributed in Europe. The homeland of Crataegus is Asian and Mediterranean countries. The most common hawthorn species found in Turkiye are shown in Table 1 and hybrids in Table 2 (Ercisli, 2004; Yilmaz et al., 2015; Caliskan et al., 2016).

Table 1. Hawthorn species are found in Turkey

Species	Species
C. tanacetifolia (Poir.) Pers	*C. meyeri* Pojark.
C. orientalis M.Bieb. Fl. taur.-caucas	*C. caucasica* C.Koch
C. x bornmuelleri Zabel in Beissner	*C. ambigua* C.A.Mey. ex Backer
C. azarolus L. Sp.	*C. heterophylloides* Pojark
C. pontica C.Koch Verh	*C. longipes* Pojark.
C. pentagyna Waldst. and Kit.	*C. microphylla* C.Koch
C. davisii Browicz	*C. rhipidophylla* Gand.
C. pseudoheterophylla Pojark.	*C. monogyna* Jacq.

Table 2. Hybrid hawthorn species in the flora of Turkey

Parents	Hybrid species
C. orientalis x *C. tanacetifolia*	*C.* x *bornmuelleri*
C. monogyna x *C. tanacetifolia*	*C.* x *yosgatica*
C. azarolus x *C. monogyna*	*C.* x *sinaica*
C. monogyna x *C. pentagyna*	*C.* x *rubrinervis*
C. microphylla x *C. rhipidophylla*	*C.* x *browicziana*
C. monogyna x *C. rhipidophylla*	*C.* x *kyrtostyla*

C. monogyna, which is found in almost all regions of Türkiye is the dominant specie (Donmez, 2004). Among species found in Turkiye, *C. tanacetifolia* is endemic to Turkiye. There are 17 species, a subspecies, two varieties and dozens of hybrids, naturally grown in Turkiye. Hawthorn, which grows naturally in mountainous and rural areas throughout Turkiye, is a medicinal fruit known among the public as heart-friendly. Hawthorn is a fruit that stands out with its high vitamin C, calcium, and antioxidant content. Its natural growing area is very wide. In Türkiye, it is found especially abundantly in the Central Anatolia (Ankara, Eskişehir), Black Sea (Amasya, Artvin), and Eastern Anatolia (Malatya, Erzurum, Van) regions (Ercisli, 2004; Bektas et al., 2017) (Figure 2).

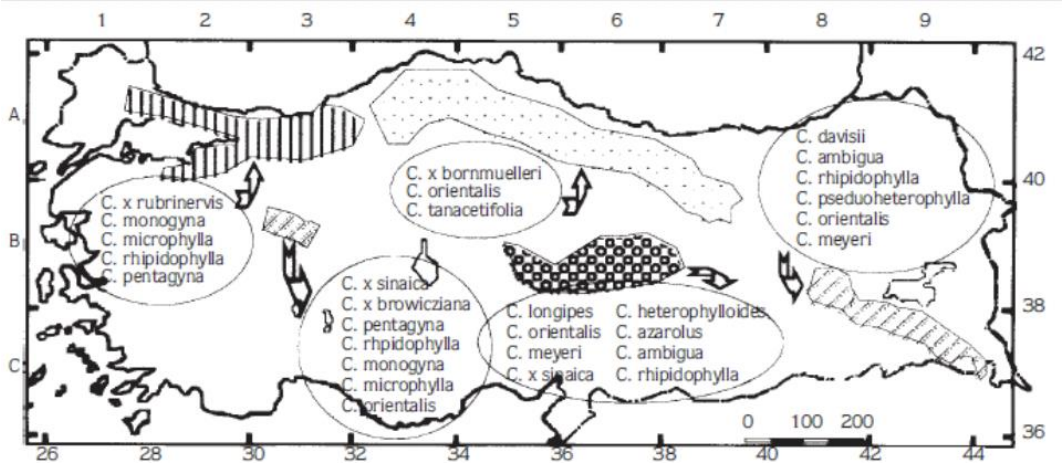


Figure 2. Hawthorn taxons found in Türkiye (Donmez, 2024).

Hawthorn is one of the most important native species of Turkiye and it is accepted as a traditional wild edible fruit. It is not only used for direct consumption, but also is processed as jam or jelly due to its rich pectin content in Turkiye or used as snack food processing because of its sweet and sour taste and rich nutrients (Gundogdu et al., 2014; Gurlen et al., 2020; Baran and Nadaroglu., 2022).

Hawthorn is characterized by a diverse array of secondary metabolites such as flavonoids, phenolics, terpenoids, and pectin that can be broadly categorized into several major chemical classes, each with distinct structural features and biological properties (Alirezalu et al., 2020; Dai et al., 2021; Kępińska-Pacelik and Biel, 2026). Therefore, hawthorn also is considered as a medicinal and food homologous fruit in both Turkiye and in the world.

Besides, hawthorn also has been used in Turkish herb for centuries, to possess the therapeutic effects prompting appetite, to support cardiovascular health. It helps to balance blood pressure, lower cholesterol, and regulate blood circulation. It has been used as antidiabetic, improve lipid metabolism disorder, antioxidant, anticancer, improve gastrointestinal function, improve cognitive impairment and anti-inflammatory (Keser et al., 2014; Mustafa et al., 2024). Its fruits can be dried and brewed as tea; its leaves and flowers are used in tincture and extract forms (Kępińska-Pacelik and Biel, 2026). (Figure 3).

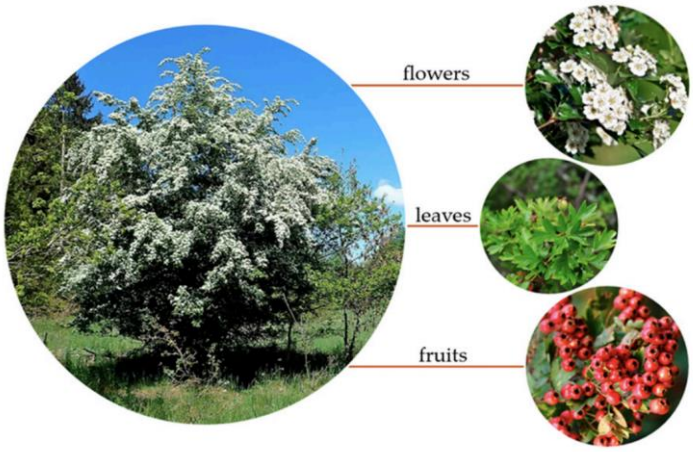


Figure 3. The used parts of hawthorn plant (Kępińska-Pacelik and Biel, 2026)

Morphologically, hawthorn fruits are very diverse and shows great differences in particular for fruit color (Figure 4). There is significant diversity among hawthorn species in terms of plant habit, vegetative and generative development, fruit ripening and fruit shape as well. This diversity leads to different characteristics being exhibited by genotypes within the same species that are propagated from seed. Hawthorn has shrub, semi-shrub, or tree forms. In terms of crown shape, there are hawthorn genotypes that are semi-circular, circular, oval, elliptical or rectangular, and in terms of plant height, their height varies between 2.5 meters to 8 meters (Yanar et al., 2011; İkinci et al., 2022).

Morphological character differentiation is the grouping and distinction of horticultural plants based on observable external and internal structural features such as shape, size, color, and texture. It is a fundamental method in classification, species identification, and variation analysis. The fruits of main hawthorn species are yellow, red, and black fruit color. However, transition between above colors is also evident (Figure 4). Fruit color is the one of the most important distinct characteristics of hawthorn species (Yanar et al., 2011; Alirezalu et al., 2020).

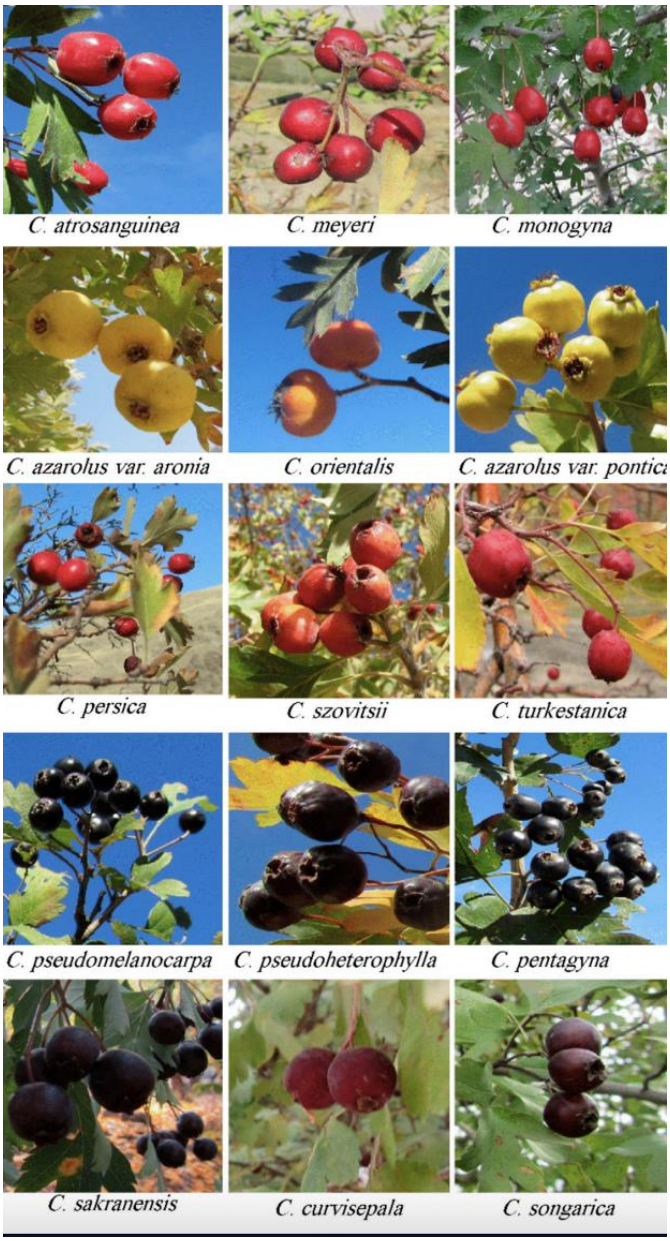


Figure 4. Different colored Crateagus fruits (Alirezalu et al., 2020).

Hawthorn species and genotypes shows great variability on leaf and fruit dimensions, leaf color, plant habitus, plant height, canopy size, presence of thorns on the shoot, branching, fruit taste, fruit shape and fruit density (Khadivi-Khub et al., 2015; Asheghi, 2022).

Containing antioxidant flavonoids, hawthorn fruit supports cardiovascular health by helping to dilate blood vessels, improve blood flow, and protect blood vessels from damage (Chang et al., 2005). It strengthens the immune system, protecting the body from damage caused by free radicals, reducing the risk of chronic diseases such as diabetes and asthma, and preventing infection.

The general benefits of hawthorn fruit include:
-Removing free radicals from the body
-Strengthening the immune system
-Preventing infection
-Defending the body against chronic inflammations such as diabetes and asthma
-May prevent kidney stone formation
-Calming the nervous system with its soothing effect
-Strengthening brain function and memory
-Preventing signs of premature aging and skin deformation
-Helps prevent the development of diseases such as cancer (Zhang et al., 2020; Li et al., 2022; Cui et al., 2024; Mustafa et al., 2024) (Figure 5).

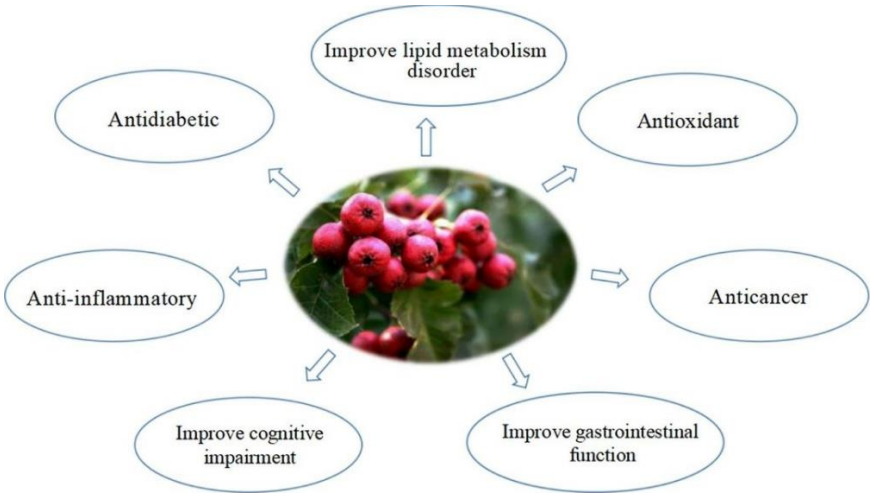


Figure 5. Traditional use of hawthorn fruits for some important ailments

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YEŞİL SENTEZ NANOPARTİKÜLLERİN SEKONDER METABOLİT ÜRETİMİNDE KULLANILMALARI

GREEN SYNTHESIS: USE OF NANOPARTICLES IN SECONDARY METABOLITE PRODUCTION

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ÖZET
Sekonder metabolitler bitkilerde üretilen, onların büyüme ve gelişmelerinde direkt etkili olmamakla birlikte farklı stres faktörlerine dayanım kazanmalarında büyük rol oynayan bileşiklerdir. Önceleri atık maddeler olarak ifade edilen ancak bitki bünyesinde çok önemli roller üstlendiğinin anlaşılmasından sonra üzerinde çalışmaların arttığı bileşiklerdir. Bu bileşiklerin insan sağlığında da çok büyük roller üstlendiğinin ortaya çıkarılması ile birlikte sekonder metabolitlere duyulan ilgi artmıştır. Günümüzde tıp, eczacılık, kozmetik, gıda ve boya sanayii olmak üzere pek çok alanda sekonder metabolitler büyük bir kullanım alanına sahiptirler. Bununla birlikte bu bileşiklerin bitkideki üretim miktarı çok düşük konsantrasyonlarda olup, farklı bitkilerin farklı kısımlarında ve dönemsel olarak değişiklik gösterdiği de bilinmektedir. Bu bileşiklerin yüksek saflıkta ve homojen miktarlarda üretilmeleri büyük önem taşımaktadır. Sekonder metabolitler uzun yıllar geleneksel yöntemlerle bitki ekstraksiyonları ile üretilmiş olmakla birlikte yukarıda değinilen dezavantajları nedeniyle araştırmalar farklı üretim yöntemlerine odaklanmıştır. Günümüzde ise bitki doku kültürü teknikleri vegetasyon dönemine bağlı kalmaksızın, küçük bir bitki parçasından yüksek saflıkta, yüksek miktarda ve homojen sekonder metabolit üretiminde avantajlı tekniklerdir. Bunlar içerisinde ise kontrollü koşullarda hücresel gelişim ve metabolik değişimlerin incelenmesine olanak sağlayan kallus ve hücre kültürleri büyük bir öneme sahiptir. Bunun yanında elisitör olarak adlandırılan, bitki besin ortamına ilave edilen bazı bileşiklerin üretilecek metabolit miktarının artırılmasını sağladığı da bilinmektedir. Bu nedenle son yıllarda bitki hücre ve doku kültürü tekniklerinde farklı elisitörlerin etkisinin incelenmesine yönelik çok sayıda çalışma yapılmaktadır. Bu uygulamalardan birisi de nanopartikül uygulamalarıdır. Nanopartiküller, 1–100 nm boyut aralığında bulunan ve yüksek yüzey alanı, artmış reaktivite, kontrollü iyon salınımı ve biyolojik sistemlerle etkin etkileşim kurabilme özelliklerine sahip materyallerdir. Özellikle metal oksit ve metal bazlı nanopartiküller; bitki gelişimi, bitki koruma, sekonder metabolit üretimi, besin elementi taşınımı ve stres toleransı gibi alanlarda önemli potansiyele sahiptirler. Nanopartikül üretiminde son zamanlarda sürdürülebilir yöntemler ve çevre dostu uygulamalar ön plana çıkmış, bu kapsamda "yeşil sentez" önem kazanmıştır. Bu şekilde bitki ekstraktları, biyolojik bileşikler ve mikroorganizmalar ile kimyasal kullanılmaksızın partikül üretmek mümkün olmaktadır. Nanometre seviyelerinde üretilebilen bu bileşikler toksisitesi düşük, çevre dostu ve biyouyumlu bileşiklerdir. Derleme niteliğindeki bu çalışma ile son yıllarda nanopartikül uygulamaları yoluyla sekonder metabolit üretimi ve nanopartiküllerin yeşil sentezine yönelik uluslararası literatürler değerlendirilmiştir.
Anahtar Kelimeler: Nanopartikül, antioksidan, fenolik bileşikler, yeşil sentez

ABSTRACT
Secondary metabolites are compounds produced in plants that, while not directly affecting their growth and development, play a significant role in their resistance to various stress factors. Initially considered waste products, their crucial roles within the plant have led to increased research on them. The discovery of their significant role in human health has further fueled interest in secondary metabolites. Today, secondary metabolites are widely used in many fields, including medicine, pharmaceuticals, cosmetics, food, and the dye industry. However, the production amounts of these compounds in plants are very low, varying in different parts of different plants and seasonally. Producing these compounds in high purity and homogeneous quantities is of great importance.

While secondary metabolites have been produced for many years through traditional plant extraction methods, research has focused on different production methods due to the disadvantages mentioned above. Today, plant tissue culture techniques are advantageous for producing high-purity, high-quantity, and homogeneous secondary metabolites from a small plant part, regardless of the vegetation period. Among these, callus and cell cultures, which allow the examination of cellular development and metabolic changes under controlled conditions, are of great importance. In addition, it is known that some compounds added to the plant nutrient medium, called elicitors, increase the amount of metabolites produced. Therefore, in recent years, numerous studies have been conducted to investigate the effects of different elicitors in plant cell and tissue culture techniques. One of these applications is nanoparticle applications. Nanoparticles are materials with a size range of 1–100 nm and possess high surface area, increased reactivity, controlled ion release, and the ability to effectively interact with biological systems. Especially metal oxide and metal-based nanoparticles; Nanoparticles have significant potential in areas such as plant growth, plant protection, secondary metabolite production, nutrient transport, and stress tolerance. Recently, sustainable methods and environmentally friendly applications have come to the forefront in nanoparticle production, and "green synthesis" has gained importance in this context. In this way, it is possible to produce particles without the use of chemicals using plant extracts, biological compounds, and microorganisms. These compounds, which can be produced at the nanometer level, are low-toxicity, environmentally friendly, and biocompatible. This review study evaluates the international literature from recent years regarding secondary metabolite production via nanoparticle applications and the green synthesis of nanoparticles.
Keywords: Nanoparticle, antioxidant, phenolic compounds, green synthesis

GİRİŞ

Sekonder metabolitler bitkilerde üretilen, onların büyüme ve gelişmelerinde direkt etkili olmamakla birlikte farklı stres faktörlerine dayanım kazanmalarında büyük rol oynayan bileşiklerdir. Önceleri atık maddeler olarak ifade edilen ancak bitki bünyesinde çok önemli roller üstlendiğinin anlaşılmasından sonra üzerinde çalışmaların arttığı bileşiklerdir. Bu bileşiklerin insan sağlığında da çok büyük roller üstlendiğinin ortaya çıkarılması ile birlikte bu sekonder metabolitlere duyulan ilgi artmıştır. Günümüzde tıp, eczacılık, kozmetik, gıda ve boya sanayi olmak üzere pek çok alanda sekonder metabolitler büyük bir kullanım alanına sahiptirler. Bununla birlikte bu bileşikler bitkide çok düşük konsantrasyonda üretilmekte olup bitkilerin farklı kısımlarında ve dönemsel olarak değişiklik gösterdiği de bilinmektedir. Bu bileşiklerin yüksek saflıkta ve homojen miktarlarda üretilmeleri büyük önem taşımaktadır.

Sekonder metabolitler uzun yıllar geleneksel yöntemlerle bitki ekstraksiyonları ile üretilmiş olmakla birlikte yukarıda değinilen dezavantajları nedeniyle araştırmalar farklı üretim yöntemlerine odaklanmıştır. Günümüzde ise bitki doku kültürü teknikleri vegetasyon dönemine bağlı kalmaksızın, küçük bir bitki parçasından yüksek saflıkta, yüksek miktarda ve homojen sekonder metabolit üretiminde avantajlı tekniklerdir. Bunlar içerisinde ise kontrollü koşullarda hücresel gelişim ve metabolik değişimlerin incelenmesine olanak sağlayan kallus ve hücre kültürleri büyük bir öneme sahiptir (Saje et al., 2000; Ramachandra Rao ve Ravishankar, 2002; Qu et al., 2006). Ayrıca araziden bağımsız, çevre faktörlerinin etkisi altında kalmaksızın bir üretim söz konusu olmakta ve özellikle belli bir doku ve organda üretilen bir maddenin bitkinin diğer kısımlarında da üretilebilmesi mümkün olabilmektedir. Tüm bu olumlu özelliklerinin yanı sıra hücre süspansiyon kültürleri ile endüstriyel anlamda sekonder metabolit üretimi halen istenilen ölçüde gerçekleşememektedir (Kieran et al., 1997). Şikonin, ginseng, saponin ve paklitaksel gibi bazı sekonder metabolitlerin ticari düzeylerde üretilebildikleri bilinmektedir (Roberts and Shuler, 1997; Verpoorte et al., 1999). Sekonder metabolitlerin ekonomik düzeylerde üretilememiş olmaları bu tekniğin önündeki en önemli problem olarak karşımıza çıkmaktadır (Callebaut et al., 1997; Kim et al., 2004). Bunun yanında kültür süresi de aşılması gereken bir diğer problem olarak görülmektedir. Hücre süspansiyon kültürlerinde istenilen başarının elde edilememiş olmasında çok sayıda mekanizmanın etkili olduğu ileri sürülmektedir. Bunlar içinde en önemlilerinin, ana bitkinin genetik olarak heterojen olması, genetik ve epigenetik stabilitenin olmaması, ana bitkinin karşılaştığı çevresel stres faktörleri ile doku farklılaşmasının yetersiz olması ve kimyasal bazı sinyal iletimlerinin olduğu düşünülmektedir (Dörnenburg and Knorr, 1995; Kim et al., 2004; Nail and Roberts, 2004).

Ayrıca bitki hücrelerinin nispeten büyük olmaları ve süspansiyon kültürlerinde çalkalama sırasında kolayca zararlanabilmelerinden dolayı da metabolit üretiminin düşebileceği belirtilmektedir (Kieran et al., 1997). Tüm bu olumsuzlara karşın uygun sistem sağlanabildiğinde in vitro teknikler bu bileşiklerin üretiminde son derece başarılı bir teknik olarak kullanılabilecektir. Sekonder metabolit üretiminde üretimin artırılmasına yönelik olarak yapılan çalışmalarda elisitör olarak adlandırılan bazı uygulamaların ortama ilave edilmesinin de etkili olacağı gösterilmektedir. Bu nedenle son yıllarda bitki hücre ve doku kültürü tekniklerinde farklı elisitörlerin etkisinin incelenmesine yönelik çok sayıda çalışma yapılmaktadır (Cormier et al., 1990; Aoyagi et al., 1996; Can ve Gürel, 2023). Bu uygulamalardan birisi de nanopartikül uygulamalarıdır.

Nanopartiküller, 1-100 nm boyut aralığında bulunan ve yüksek yüzey alanı, artmış reaktivite, kontrollü iyon salınımı ve biyolojik sistemlerle etkin etkileşim kurabilme özelliklerine sahip materyallerdir (Khan et al., 2019). Özellikle metal oksit ve metal bazlı nanopartiküller; bitki gelişimi, bitki koruma, sekonder metabolit üretimi, besin elementi taşınımı ve stres toleransı gibi alanlarda önemli potansiyele sahiptirler (Parisi et al., 2015). Nanopartiküllerin kontrollü iyon salınımı ve hücresel sinyal mekanizmaları aracılığıyla in vitro gelişim süreçlerini etkileyebileceği, kallus oluşumu, organogenesis, somatik embriyogenesis ve sekonder metabolit üretimi üzerine etkili olabileceği belirtilmiştir (Kim et al., 2017). Nanometre seviyelerinde üretilebilen bu bileşikler toksisitesi düşük, çevre dostu ve biyouyumlu bileşiklerdir (Iravani, 2011; Ahmed et al., 2016).

Nanopartiküllerle Sekonder Metabolit Üretimine Yönelik Çalışmalar

NP'lerle sekonder metabolit üretimine yönelik çalışmalar incelendiğinde bu çalışmaların yoğun olarak özellikle son on yıl içerisinde yapılmakta olduğu görülmektedir. Bunlar farklı bitkilerde ve farklı sekonder bileşenlerin çeşitli NP'ler ile artırılmasına yönelik çalışmalardır. Bu araştırmalardan birisinde Raei et al. (2014), *Aloe vera* L.bitkisinin en önemli sekonder metaboliti olan alloin üzerine NP uygulamalarının hücre kültürlerindeki etkisini incelemişlerdir. Nano gümüş ile muamele edilen kültürlerde 48 saat içinde aloin içeriğinin %43,7'ye yükseldiğini belirtmişlerdir. 48 saatlik Nano-TiO2 uygulamasının ise en fazla alloin üretimini sağladığı ifade edilmiştir. Bir araştırmada ise gümüş ve altın (Ag-AuNP), NP lerin birlikte kullanıldığında fenolik ve flavonoid içeriğinin maksimum düzeyde biriktiği belirlenmiştir (Fazal, 2016).

Fındık (*Corylus avellana*) da hücre süspansiyon kültürünün 5 mg/L Ag NP lere maruz kalması ile taksol üretimi önemli ölçüde artmıştır (Jamshidi et al., 2016). Bakır ve Kobalt NP'ler ise *Mentha longifolia*'da uçucu yağ üretimini yoğunlaştırmıştır (Talankova-Sereda, 2016). Hussain et al. (2017) yapmış oldukları çalışmalarında özellikle Ag, Cu ve Au olmak üzere metal NP'lerin sekonder metabolit üretiminde, toplam fenolik ve flavonoid içeriğinde artış sağladığını belirtmişlerdir.

AgNP'ler, *Catharanthus roseus* L'nin savunma tepkilerini tetikleyerek sekonder metabolitlerinin üretimini indükleyebilen bir uyarıcı olduğu belirlenmiş ve 75 mg/L AgNP ile muamele edilen eksplantlarda yüksek vinblastin içeriği görülmüştür (Shahin, 2018).

Mangan NP'ler (MnNPs) daha az üzerinde çalışılan bir NP olup, bu alanda yapılmış bir araştırmada 25 mg/L konsantrasyonundaki Mn_2O_3 NP'lerin antioksidan enzimleri aktive ederek *Atropa belladonna* bitkisinde sekonder metabolitleri artırdığı belirtilmiştir (Tian et al., 2018).

Ali et al. (2019), *Caralluma tuberculata'*nın kallus kültürlerinde sekonder metabolit üretimi için gümüş nanopartiküllerin (AgNPs) etkisini incelemişlerdir. Araştırma sonucunda 90 ug/l AgNPs varlığında MS ortamında oluşturulan kallus kültürlerinde daha yüksek fenolik madde (3,0 mg), flavonoid (1,8 mg), fenilalanin amonyaliyaz aktivitesi (5,8 U/mg) ve antioksidan aktivite (%90) üretimi olduğunu belirlemişlerdir.

Stevia kültürlerinde CuONP (20 mg/L) ve ZnONP (2 mg/L)'nin toplam fenolik, toplam flavonoid içeriği, steviol glikozit konsantrasyonunu artırdığı bildirilmiştir (Ahmad et al., 2020).

Farghaly et al. (2020) ise nar da kallus kültürlerinde ZnO nanopartiküllerinin redoks enzim sistemi üzerine etkilerini araştırmışlardır. MS ortamına 0, 10 ve 150 $\mu g\ mL^{-1}$ ZnO nanopartikülleri ilave etmişler ve nanopartiküllerin süperoksit dismutaz, katalaz ve fenilalanin amonyaliyaz aktivitelerini artırdığını belirlemişlerdir. Bunun yanında yüksek nanopartikül dozlarının oksidatif stres oluşturabileceği ve bazı mineral elementlerin alımını baskılayabileceğine de işaret etmişlerdir.

H. perforatum hücre kültürlerine Ag, Au, Cu, Pd, CeO_2, CuO, TiO_2 ve ZnO NP uygulaması yapılması sonrası Ag NP'ler bisksanton, gankaonin O ve fusaroskyrin'in hücresel birikimini artırmıştır.

Hiperksanton C miktarı Au ile, apigenin miktarı Cu ile emodin antron CeO_2 ile artarken; dihidroksidimetoksiksanton I CuO ile, kuersetin TiO_2 ile ve gallik asit ise ZnO uygulamaları ile artırılmıştır. Araştırmacılar buradan yola çıkarak NP uygulamalarının NP türüne ve bileşiğe göre değişmekle birlikte uyarıcı etkilerinin bulunduğunu belirtmişlerdir (Kruszka et al., 2022).
Prasad et al. (2024), yapmış oldukları çalışmalarında çok sayıda bitkide farklı NP lerin metabolit üretiminde etkili olduğuna değinmişlerdir.
Al Qudah et al. (2025), Ürdün'e özgü tıbbi bir çalı olan ve önemli farmasötik potansiyele sahip olan *Origanum petraeum* Danin de gümüş (Ag) ve bakır (Cu) olmak üzere iki tip nanopartikülün sekonder metabolit birikimi üzerine etkisini incelemişlerdir. Murashige ve Skoog ortamına ilave edilen NP'lerden 100 mg/L'deki AgNP'lerin büyümeyi teşvik ederek mikro sürgün sayısını 11,6'ya ve sürgün yüksekliğini 9,22 cm'ye çıkardığı; 50 mg/L CuNP'lerin, α-terpinil asetat (%29,23) ve geranil asetat (%12,76) dahil olmak üzere monoterpenleri artırırken, 50 mg/L AgNP'ler kariofilen oksit (%28,45) gibi seskiterpenleri artırdığını belirlemişlerdir.
NP üretiminde son zamanlarda sürdürülebilir yöntemler ve çevre dostu yaklaşımlar ön plana çıkmış, bu kapsamda "yeşil sentez" yaklaşımları önem kazanmıştır. Bu yaklaşım, kimyasal sentez yöntemlerine göre daha çevre dostu ve sürdürülebilir bir yöntem olarak değerlendirilmektedir (Iravani, 2011; Mittal et al., 2013; Ahmed et al., 2016). Bu yaklaşımla bitki ekstraktları, biyolojik bileşikler ve mikroorganizmalar ile kimyasal kullanılmaksızın NP üretmek mümkün olmaktadır.
Yeşil sentez NP ile sekonder metabolit üretimi üzerine çalışan Saeed et al. (2021) deve dikeni (*Silybum marianum*) bitkisi kallus kültürlerinde yeşil sentez ve kimyasal sentez ZnO NP'lerin etkilerini incelemişlerdir. Araştırmada yeşil sentez ZnO NP'lerinin kallus gelişimi, sürgün gelişimi, toplam fenolik madde, flavonoid birikimi ve antioksidan aktiviteyi artırdığı bildirilmiştir. Ayrıca kallus kültürlerinde protein miktarının ve biyolojik aktivitenin de yükseldiği belirtilmiştir. Araştırıcılar, yeşil sentez NP'lerin kimyasal sentez NP'lere göre daha olumlu sonuçlar verdiğini de vurgulamışlardır.
Ullah et al. (2024), yeşil sentez demir oksit (FeO-NPs)'in çeltik (*Oryza sativa*) bitkisi kallus kültürlerinde FeO NP'lerinin MS ortamında klasik Fe-EDTA kaynağı yerine kullanılabileceği ve kallus oluşumu ile rejenerasyonu artırdığı bildirilmiştir. Araştırıcılar 15 ppm FeO-NPs uygulamasının kallus kontaminasyonunu %80 oranında azalttığını, kallus ağırlığını ve sürgün rejenerasyonunu önemli düzeyde artırdığını belirtmişlerdir. Ayrıca FeO NP'lerinin antioksidan enzim aktivitelerini de artırdığı ifade edilmiştir.
Zhu et al. (2024), *Rehmannia glutinosa* bitkisinin kök tüylerinde bulunan ve ilaç sanayiinde kullanılan iridoid glikozit ve feniletanoid glikozit gibi aktif bileşiklerin üretiminde yeşil sentez NP uygulamalarının etkisini incelemişlerdir. Elisitör olarak gümüş nanopartiküller (AgNPs) kullanılmıştır. Uygulama sonrası biyokütle, renk, sekonder metabolitler, antioksidan aktivite, sükroz metabolizması ve fitohormonla ilgili gen ekspresyonu incelenmiştir. Araştırma sonucunda verbascosid, toplam feniletanol glikozitleri ve toplam sikloartenoid içeriğinin arttığını belirten araştırmacılar, uygun konsantrasyondaki Pp-AgNP lerin tüylü kökler tarafından üretilen sekonder metabolit içeriğini iyileştirmek için etkili bir uyarıcı olarak kullanılabileceğini ifade etmişlerdir.

Yeşil Sentez Nanopartikül Üretim Süreci Ve Yapı Doğrulamaları
Bitki ekstraktlarından NP sentezlemek için katı faz yöntemleri ve çözelti fazı yöntemleri olmak üzere iki ana yaklaşım kullanılmaktadır.
Sentez süreci, metal öncüllerinin bitki özlerinde bulunan biyomoleküllerle etkileşimini içermektedir. Genel olarak, bitkilerde ve bitki özlerinde NP'lerin sentezi üç aşamada gerçekleşmektedir (Azad et al., 2023):

1. Aktivasyon aşaması: Bu aşamada fenolik asitler gibi ikincil metabolitler elektron vererek metal iyonlarının indirgenmesini başlatmaktadır. Bu durum çekirdeklenme sürecini kontrol etmeye yardımcı olarak küçük, kararlı NP'lerin oluşmasına neden olmaktadır.

2. Büyüme evresi: Küçük NP'ler kendiliğinden daha büyük parçacıklar halinde birleşmekte ve bu sırada termodinamik kararlılık artmaktadır. Bu evrede flavonoidler ve tanenler gibi stabilize edici bileşiklerin bulunması, aşırı kümelenmeyi önlemeye ve homojen boyutlu nanopartiküllerin oluşumunu sağlamaya yardımcı olmaktadır.

3. Sonlandırma aşaması: Bu kritik aşama, büyük ölçüde bitki ekstraktının içsel stabilizasyon özelliklerine ve metal öncülleriyle etkileşimine bağlı olarak nanopartiküllerin son morfolojisini belirlemektedir (Makarov et al., 2014).

Nanopartikül Karakterizasyonu

Elde edilen NP'lerin yapı doğrulama ve aydınlatılması için morfolojik, spektrofotometrik ve elementel doğrulama testleri yapılmaktadır.

- UV-Vis spektrofotometre: NP oluşumunun ilk doğrulaması için kullanılmaktadır. Özellikle AgNP sentezinde yüzey plazmon rezonans pikinin izlenmesi önemlidir.
- FTIR analizi: Bitki ekstraktından gelen fonksiyonel grupların NP yüzeyindeki rolünü belirlemek için kullanılmaktadır.
-XRD analizi: Kristal yapı ve faz doğrulaması için kullanılmaktadır.
- SEM analizi: Partikül morfolojisi ve yaklaşık boyut dağılımının belirlenmesinde kullanılmaktadır.
- EDX analizi: Elementel bileşimin doğrulanmasında kullanılmaktadır.
-Zeta potansiyel analizi: Kolloidal stabilitenin belirlenmesinde kullanılmaktadır.

NP doğrulama sonrasında elde edilmiş NP'ler genellikle besin ortamına uygun membran filtrelerden geçirilerek sterilize edildikten sonra, otoklavlanmış ve yaklaşık 45–50 °C'ye soğutulmuş ortama ilave edilmektedirler.

NP'lerin besin ortamına ilave edileceği dozlar araştırmalarda oldukça değişkendir. Nitekim AgNP ve CuO-NP gibi antimikrobiyal etkisi güçlü nanopartiküllerin yüksek dozlarda bitkiler üzerinde fitotoksisite riski oluşturduğu bilinmektedir (Dimkpa et al., 2012). Farghaly et al. (2020), ZnO nanopartikülleriyle yaptıkları çalışmalarında 10 ve 150 µg mL^{-1} aralığındaki dozları kullanmış ve düşük ve yüksek dozların redoks enzimleri ve mineral alımı üzerinde farklı etkiler oluşturduğunu bildirmişlerdir. Ullah et al. (2024), yeşil sentez FeO nanopartiküllerinde 15 ppm uygulamasının MS ortamında kallus kontaminasyonunu azalttığı, kallus gelişimi ve rejenerasyonu artırdığını bildirmişlerdir.

SONUÇ

Günümüzde tıp, eczacılık, kozmetik, gıda ve boya sanayii olmak üzere pek çok alanda büyük bir kullanım alanına sahip olan sekonder metabolitlerin yüksek miktar ve saflıkta üretilebilmeleri büyük önem taşımaktadır. Son yıllarda bu amaçla yeni teknikler kullanılmaktadır. Bu uygulamalardan birisi de nanopartikül uygulamaları olup burada da sürdürülebilir yöntemler ve çevre dostu uygulamalar ön plana çıkmış ve "yeşil sentez" önem kazanmıştır. Bu şekilde bitki ekstraktları, biyolojik bileşikler ve mikroorganizmalar ile kimyasal kullanılmaksızın partikül üretmek mümkün olmaktadır. Nanometre seviyelerinde üretilebilen bu bileşikler toksisitesi düşük, çevre dostu ve biyouyumlu bileşiklerdir.

Güncel araştırmalar, fitotoksisite olmaksızın biyolojik aktiviteyi artırma yöntemi olarak NP uygulamasının, biyoaktif kimyasalların üretimini teşvik etmenin bir yolu olduğunu göstermektedir. Bununla birlikte, nanomalzemelerin uyarıcı olarak kullanılmasının ekosistemler ve insanlar üzerindeki olası etkileri konusunda daha fazla araştırmaya ihtiyaç duyulmaktadır (Rivero-Montejo et al., 2021).

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ARONYA (ARONİA MELANOCARPA)'NIN BESİN DEĞERİ VE DEĞERLENDİRME YÖNTEMLERİ

NUTRITIONAL VALUE AND EVALUATION METHODS OF CHOKEBERRY (ARONIA MELANOCARPA)

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ÖZET
Aronya (Aronia melanocarpa), Rosaceae familyasına ait Kuzey Amerika orjinli çalı formunda bir bitkidir. İlk olarak 1900'lerde Rusya'da ve daha sonra 1950'lerde Doğu Avrupa ülkelerinde yetiştirilmeye başlanmıştır. Yüksek besin değeri ve sağlık açısından faydalı bir bitki olarak bilinmesi nedeniyle, küresel çapta büyük ilgi görmüş ve günümüzde hem meyve hem de tıbbi amaçlarla kullanmak üzere yetiştiriciliği artmıştır. Aronya'nın büyük ölçekli yetiştirilmesi, gıda ürünlerinde kullanımı için gerekli ham maddeleri sağlamaktadır. Giderek artan sayıda insan, tarımsal üretimden tüketici tüketimine kadar fonksiyonel gıdaların tüm tedarik zincirini dikkate almaktadır. Meyvelerin besin profili, hem çeşit farklılıklarından hem de yetiştirme koşullarından büyük ölçüde etkilenir. Türkiye için yeni bir tür olan aronya diğer üzümsü meyveler gibi birim alandan yüksek getiriye sahiptir. Meyveleri, özellikle siyanidin-3-O-galaktosid gibi antosiyaninler içeren polifenoller açısından zengindir. Polifenolik bileşikler, mükemmel antioksidan kapasiteleriyle öne çıkar ve aronyanın antioksidan aktivitesinin ana malzeme temelini oluşturur. Özellikle antosiyaninler, güçlü bir doğal antioksidan kaynağıdır. Fenolik asitler, aronya polifenollerinin %7,5'ini oluşturur ve klorojenik asit, meyvede tespit edilen birincil bileşiktir. Ayrıca antiinflamatuar, antioksidan, hepatoprotektif, kardiyometabolik düzenleyici, nöroprotektif ve antitümör etkiler de dahil olmak üzere geniş bir biyolojik aktiviteye sahiptir. Aronya zengin fitokimyasal içeriği sayesinde, doğal antioksidan katkı maddeleri, spor beslenme ürünleri, gıda koruma, doğal pigmentler ve gıda renklendiricileri de dahil olmak üzere tarım-gıda sektöründe çeşitli alanlarda kullanılmaktadır. Gıda endüstrisinde aronya, meyve suları, yoğurtlar, reçeller, şuruplar ve çay içecekleri gibi çeşitli ürünlerin geliştirilmesinde kullanılmaktadır.
Anahtar Kelimeler: Aronya, besin içeriği, meyve değerlendirme şekilleri

ABSTRACT
Chokeberry (*Aronia melanocarpa*) is a shrub-like plant native to North America, belonging to the Rosaceae family. It was first cultivated in Russia in the 1900s and later in Eastern European countries in the 1950s. Known for its high nutritional value and health benefits, it has gained significant global interest, and its cultivation has increased today for both fruit production and medicinal purposes. Large-scale chokeberry cultivation provides the necessary raw materials for its use in food products. An increasing number of people are considering the entire supply chain of functional foods, from agricultural production to consumer consumption. The nutritional profile of the fruit is largely influenced by both variety differences and growing conditions. Chokeberry, a new species for Turkey, has a high yield per unit area, like other berry fruits. Its fruits are rich in polyphenols, especially anthocyanins such as cyanidin-3-O-galactoside. Polyphenolic compounds stand out with their excellent antioxidant capacity and form the main material basis of chokeberry's antioxidant activity. Anthocyanins, in particular, are a powerful natural antioxidant source. Phenolic acids constitute 7.5% of chokeberry polyphenols, and chlorogenic acid is the primary compound detected in the fruit. It also possesses a wide range of biological activity, including anti-inflammatory, antioxidant, hepatoprotective, cardiometabolic regulatory, neuroprotective, and antitumor effects. Thanks to its rich phytochemical content, chokeberry is used in various fields in the agro-food sector, including natural antioxidant additives, sports nutrition products, food preservation, natural pigments, and food colorings. In the food industry, chokeberry is used in the development of various products such as fruit juices, yogurts, jams, syrups, and tea.
Keywords: Chokeberry, nutritional content, ways to utilize fruit.

THE IMPORTANCE OF THE MAJOR CHEMICAL COMPONENTS IN THE ESSENTIAL OILS OF THREE SALVIA SPECIES ENDEMIC TO TÜRKİYE

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ABSTRACT
Salvia L., one of the largest genera of the Lamiaceae family, encompasses numerous taxa of importance in the fields of medicine, pharmaceuticals, food, cosmetics, and perfumery due to its aromatic properties and rich secondary metabolite content. It is stated that approximately half of the *Salvia* taxa found in the flora of Türkiye are endemic. This high rate of endemism makes it important to investigate the chemical diversity, biological activity, and economic use potential of *Salvia* genetic resources specific to Türkiye. One of the main secondary metabolite groups that determine the biological and economic value of *Salvia* species is essential oils. Essential oils are complex mixtures of natural compounds consisting mostly of monoterpenes, oxygenated monoterpenes, sesquiterpenes, and their oxygenated derivatives. The qualitative and quantitative distribution of these compounds can be decisive in determining the biological activity as well as the characteristic scent and aroma properties of the essential oil. This study, conducted to investigate the essential oil components and their importance in three endemic sage species of the Flora of Türkiye [*Salvia cyanescens* Boiss. & Balansa, *Salvia hypargeia* Fisch. & C.A.Mey. and *Salvia absconditiflora* (Montbret & Aucher ex Benth.) Greuter & Burdet], involved obtaining the essential oils of these species by hydrodistillation, and determining their chemical composition using GC-MS. The biological activity and uses of the essential oil components were evaluated using current literature data. The essential oils of *S. cyanescens* and *S. hypargeia* were characterized by oxygenated sesquiterpenes, while the essential oil of *S. absconditiflora* was characterized by sesquiterpene hydrocarbons. Spathulenol, ledene oxide, 6-epi-shyobunol, α-acorenol, caryophyllene oxide, caryophyllene, β-copaene, and humulene were recorded as the main components in the essential oils examined. Spathulenol, ledene oxide, 6-epi-shyobunol, α-acorenol, caryophyllene oxide, β-caryophyllene, β-copaene, and α-humulene are sesquiterpenes and oxygenated sesquiterpenes that contribute to the biological activity of essential oils. Among these compounds, β-caryophyllene, caryophyllene oxide, α-humulene, and spathulenol are particularly important for the development of pharmaceutical products, natural preservatives, and biopesticides due to their anti-inflammatory, antimicrobial, antioxidant, cytotoxic, and insecticidal effects.
Keywords: *Salvia* L., endemic, GC-MS, sesquiterpene, β-caryophyllene

INTRODUCTION
The genus *Salvia* L. (Lamiaceae) includes numerous species valued in medicinal, aromatic, food, cosmetic, and perfumery, and derives its economic importance largely from the secondary metabolites it accumulates. Phenolic acids, flavonoids, diterpenes, and triterpenes, as well as essential oils, are the main metabolite groups determining the biological and economic value of *Salvia* species. Essential oils are complex natural mixtures consisting mostly of monoterpene hydrocarbons, oxygenated monoterpenes, sesquiterpene hydrocarbons, oxygenated sesquiterpenes, and to a lesser extent, phenylpropanoids and other volatile compounds (Bakkali et al., 2008; Dhifi et al., 2016). The qualitative and quantitative distribution of these compounds determines the fragrance and aroma characteristics of the plant, as well as influencing the antimicrobial, antioxidant, anti-inflammatory, cytotoxic, and insecticidal activity of the essential oil.
Essential oil yield and chemical composition are not solely dependent on species or genotype but can vary under the influence of numerous factors such as the plant's growth stage, the plant organ used, the climate and soil characteristics of the growing environment, geographical origin, harvest time, drying conditions, and isolation method (Figueiredo et al., 2008). Therefore, it is possible for different chemotypes to appear in the essential oils of different populations of the same species. This variability in the chemical profile is important for the standardization and industrial use of essential oils, as well as for evaluating chemotaxonomic relationships between species.

Hydro distillation of essential oils and their analysis by gas chromatography-mass spectrometry (GC-MS) is a widely used approach for both identifying compounds and revealing chemical differences between species and populations.

This study was conducted to comparatively determine the essential oil compositions of *Salvia cyanescens* Boiss. & Balansa, *Salvia hypargeia* Fisch. & C.A.Mey., and *Salvia absconditiflora* (Montbret & Aucher ex Benth.) Greuter & Burdet, all endemic to the flora of Türkiye.

MATERIALS AND METHODS

Species (*Salvia cyanescens* Boiss. & Balansa, *Salvia hypargeia* Fisch. & C.A.Mey. and *Salvia absconditiflora* (Montbret & Aucher ex Benth.) Greuter & Burdet) were collected from the Yozgat/Türkiye flora during the full flowering period in June-July. The above-ground parts (herba) of the plants obtained from natural environments were dried in the shade, and average 50 g plant samples were subjected to water distillation for 3 hours using a Clevenger apparatus.

The component analysis of the essential oils obtained from the plants collected within the scope of the research was determined by GC/MS (Gas Chromatography/Mass Spectrometry). Chromatographic processes were performed using an Agilent Technologies 6890A GC system with an Agilent Technologies 5975C network mass selective detector and an HP5-MS capillary fused silica column (length 30 m; inner diameter 0.25 mm; film thickness 0.25 µm). 5% phenyl-mathylpolysiloxane was used for the analysis of essential oils. The column temperature was planned to increase from 60°C to 240°C in increments of 4°C/minute. Helium was used as the carrier gas at a flow rate of 1 mL/minute; the injector temperature was 250°C and the split ratio was 1:10. Mass spectra were obtained at an ionization energy of 70 eV, and the scanned mass range was set to 50-550 m/z. Characterization of the components in the essential oils was performed using electronic libraries (WILEY, NIST).

RESULTS AND DISCUSSION

The chemical composition of essential oils obtained by water distillation from the flowering above-ground parts of endemic *Salvia s*pecies evaluated within the scope of the study was determined by GC-MS. In the essential oil obtained from the herb of *S. cyanescens*, spathulenol was recorded as the main component with 31.07%, followed by ledene oxide and caryophyllene oxide. In the essential oil obtained from the above-ground parts of *S. hypargeia*, 6-epi-shyobunol and β-guaiene had the highest value among the 10 components that make up almost all the oil. These two components were followed by α-acorenol, γ-elemene, ledene oxide, and caryophyllene oxide. GC-MS analysis of the essential oil obtained from the aerial parts of *S. absconditiflora* revealed caryophyllene, caryophyllene oxide, spathulenol, and β-copaene as the main components.

Table 1. Comparison of Chemical Component Groups in the Essential Oils according to Examined Species (%)

Component group	*S. cyanescens*	*S. hypargeia*	*S. absconditiflora*
Monoterpene hydrocarbons	0.63	0.00	0.00
Oxygenated monoterpenes	12.66	0.00	0.00
Sesquiterpene hydrocarbons	1.01	37.22	58.13
Oxygenated sesquiterpenes	76.12	57.76	34.39
Other terpenoid hydrocarbons	0.59	0.00	0.00
Other oxygenated terpenoids	5.92	5.01	7.46
Non-terpenoid compounds	1.90	0.00	0.00

When Table 1 is examined, it is seen that there are significant differences between species in terms of the component groups of essential oils. In *S. absconditiflora* essential oil, oxygenated sesquiterpenes constituted the highest proportion (76.12%); followed by oxygenated monoterpenes (12.66%) and other oxygenated terpenoids (5.92%). *S. hypargeia* essential oil consisted mainly of oxygenated sesquiterpenes (57.76%) and sesquiterpene hydrocarbons (37.22%). In *S. absconditiflora*, sesquiterpene hydrocarbons were the most dominant component group with 58.13%, while the proportion of oxygenated sesquiterpenes was determined as 34.39%.

The proportion of other oxygenated terpenoids varied between 5.01–7.46% in the species. Monoterpene hydrocarbons, other terpenoid hydrocarbons, and non-terpenoid compounds were detected in low proportions only in *S. cyanescens* essential oil. The calculated total component ratios ranged from 98.83–99.99%, indicating that the chemical composition of the essential oils is largely defined.
Türkiye is one of the important centers for *Salvia* genetic resources due to its high species diversity and endemism rate. The essential oil compositions of some *Salvia* species endemic to Türkiye have been previously investigated, and significant differences in the ratios of monoterpene and sesquiterpene groups have been reported among the species. Demirci et al. (2003) examined the essential oils of six endemic *Salvia* species and determined that caryophyllene oxide is one of the main compounds in the essential oil of *Salvia hypargeia* Fisch. & C.A.Mey. Subsequent studies have shown that *S. hypargeia* has remarkable chemical diversity in terms of non-volatile bioactive metabolites such as ferruginol, lupeol, and rosmarinic acid, in addition to its volatile compounds (Bakir et al., 2020). However, the biological and technological importance of the sesquiterpenes found in the essential oil of the species has not yet been evaluated in sufficient detail. Research conducted on *Salvia absconditiflora* (Montbret & Aucher ex Benth.) Greuter & Burdet reveals significant chemical variability in this endemic species. In populations collected from different regions of Türkiye, α-pinene, camphene, 1,8-cineol, camphor, and borneol were identified as common compounds; while the proportions of sesquiterpenes such as β-caryophyllene, caryophyllene oxide, β-edesmol, and valeranone were reported to vary depending on the population (Kaya et al., 2022). In another study, compounds such as 1,8-cineol, caryophyllene oxide, and spathulenol were identified in the essential oil of *S. absconditiflora*, and it was noted that the *Salvia* essential oils examined showed species- and composition-dependent activity against microorganisms (Demirpolat, 2023). Recent studies also indicate that *S. absconditiflora* essential oil has potential in terms of antibacterial, antibiofilm, and antiquorum-sensing properties (Çınar et al., 2024). However, the variation in essential oil composition according to geographical origin and environmental conditions necessitates the separate characterization of the chemical profile of each new population.

The significance of the main essential oil components identified in the *Salvia* species studied:
Ledene oxide: An oxygenated sesquiterpene that can be found in significant amounts in the essential oils of various medicinal and aromatic plants. While essential oils containing this compound have been reported to exhibit antioxidant, antimicrobial, anti-inflammatory, and cytotoxic activities, these biological effects are not solely due to ledene oxide but also to additive and synergistic interactions between essential oil components (Servi et al., 2020; Todorova et al., 2022; Judžentienė, 2025).

Spathulenol: An oxygenated sesquiterpene alcohol found in the essential oils of many medicinal and aromatic plants. Studies at the isolated compound level have shown anti-inflammatory, antiproliferative, antimycobacterial, and antibacterial activity against some microorganisms. However, it has been reported that antimicrobial activity can vary depending on the target microorganism and possible synergistic interactions with other components in the essential oil (Nascimento et al., 2018; Dzul-Beh et al., 2019; Carev et al., 2023; Da Silva et al., 2023).

6-epi-Shyobunol: This is an oxygenated sesquiterpene alcohol that can reach significant concentrations in the essential oils of various aromatic plants. While antioxidant, antimicrobial, and allelopathic activities have been reported in essential oils containing this compound in high concentrations, evidence regarding the biological activity of 6-epi-shyobunol at the pure compound level is limited; therefore, it has been suggested that these effects may result from additive or synergistic interactions with other essential oil components (Assaeed et al., 2020; Saleh et al., 2020; Abd-ElGawad et al., 2021).

β-Guaiene: A guaiane-type sesquiterpene hydrocarbon found in the essential oils of many aromatic plants, it is important for the chemical characterization of essential oils and the determination of chemotype differences. While various biological activities have been reported in some essential oils containing β-guaiene, and in silico findings have been obtained regarding the interaction of this compound with antibacterial targets, experimental studies confirming the pharmacological activity of pure β-guaiene are limited (Lv et al., 2022; Dam et al., 2025).

β-Copaene:A tricyclic sesquiterpene hydrocarbon found in the essential oils of various aromatic plants, it is particularly important for the chemical characterization of essential oils and the evaluation of chemotype differences. While antioxidant, antimicrobial, and cytotoxic activities have been reported in some plant extracts and essential oils containing β-copaene, experimental evidence demonstrating that these effects are directly attributable to pure β-copaene is limited. However, there are in silico findings supporting the potential interaction of β-copaene with acetylcholinesterase (Arora & Pandey-Rai, 2014; Hussein et al., 2019; Reddy et al., 2023).

Caryophyllene oxide: An oxygenated sesquiterpene commonly found in essential oils, studies at the pure compound level show that it possesses antibacterial, antioxidant, anti-inflammatory, and especially cytotoxic/antiproliferative activities. While it has been reported to influence cell death mechanisms such as apoptosis, oxidative stress, and ferritinophagy-mediated ferroptosis in various cancer cell lines, it should be noted that its biological activity varies depending on the concentration and experimental system (Côté et al., 2017; Xiu et al., 2022; Ramírez-Santos et al., 2024).

β-Caryophyllene: A bicyclic sesquiterpene hydrocarbon commonly found in the essential oils of many medicinal and aromatic plants, it is of biological importance, particularly due to its selective agonist status for the cannabinoid type-2 (CB2) receptor. Studies at the pure compound level have revealed that β-caryophyllene can exhibit CB2-mediated anti-inflammatory and analgesic effects, as well as antioxidant, immunomodulatory, and antiproliferative properties. However, its antimicrobial activity varies depending on the target microorganism, and evidence regarding its anticancer effects is largely preclinical (Gertsch et al., 2008; Fidyt et al., 2016; Mannino et al., 2021). However, β-caryophyllene and β-caryophyllene oxide have been reported to be important insecticidal compounds (Balasubramani et al., 2018).

CONCLUSION

The essential oils of the endemic species *S. cyanescens*, S. *hypargeia*, and *S. absconditiflora*, which are part of the Turkish flora, exhibit significant chemical diversity in terms of both their main components and the distribution of sesquiterpene groups. The characterization of *S. cyanescens* and *S. hypargeia* essential oils by oxygenated sesquiterpenes, and *S. absconditiflora* essential oil by sesquiterpene hydrocarbons, indicates the presence of different essential oil profiles among these species. The identification of major components such as spathulenol, ledene oxide, 6-epi-shyobunol, α-acorenol, caryophyllene oxide, β-caryophyllene, β-copaene, and α-humulene are important for revealing the chemical diversity and potential uses of these endemic species. Literature data indicate that β-caryophyllene, caryophyllene oxide, α-humulene, and spathulenol possess remarkable biological properties in terms of anti-inflammatory, antimicrobial, antioxidant, cytotoxic, and/or insecticidal activities. However, it should be considered that the biological effects of essential oils may depend not only on a single main component but also on the concentrations of the components and the additive, synergistic, or antagonistic interactions between them. The findings show that these endemic *Salvia* species, specific to Türkiye, are valuable genetic resources for essential oil and natural product research and have the potential to be evaluated in advanced biological activity and toxicity studies, especially for pharmaceutical, cosmetic, food, natural preservative, and biopesticide applications.

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EFFECTS OF PRECOOKED LENTIL AND COMMON BEAN FLOUR BLENDS ON THE NUTRITIONAL, PHYSICAL, AND TEXTURAL PROPERTIES OF MUFFINS

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ABSTRACT
Precooked pulse flours can improve the nutritional value of bakery products, although complete replacement of wheat flour may impair technological quality. This study investigated muffins produced with precooked yellow lentil flour (YLF) and common bean flour (CBF) blended at 0:100, 25:75, 50:50, 75:25, and 100:0 ratios as complete replacements for wheat flour. A wheat-flour muffin was used as the control. Batter properties and muffin chemical, physical, color, textural, and sensory characteristics were evaluated. The protein and ash contents of the pulse-based muffins ranged from 21.36% to 25.57% and from 1.72% to 2.34%, respectively. The corresponding values in the control were 7.56% and 1.13%, while moisture was not significantly affected by formulation. Increasing the YLF proportion raised batter pH, reduced batter density, increased protein content, and enhanced crumb yellowness. Pulse-based muffins had lower baking loss than the control. Their volumes ranged from 22.67 to 33.67 mL, whereas the control volume was 65.00 mL. Similarly, their specific volumes ranged from 0.71 to 1.07 mL/g, compared with 2.11 mL/g in the control, while their density increased. Pulse flour use produced darker crusts and crumbs, increased hardness and chewiness, and reduced springiness, cohesiveness, and resilience. Among the pulse-based formulations, YLF0:CBF100 provided the highest volume and specific volume, whereas YLF25:CBF75 achieved the highest overall acceptability (2.6/5). Overall, precooked YLF and CBF enabled the production of protein-enriched muffins without wheat flour, but complete replacement reduced volume, softness, and sensory acceptance.
Keywords: Yellow lentil flour; common bean flour; muffin; pulse flour

INTRODUCTION
Pulses are dry edible seeds of leguminous crops and include lentils, common beans, chickpeas, and peas. They are valuable sources of plant protein, complex carbohydrates, dietary fiber, minerals, and various phytochemicals. In addition to their nutritional value, pulse flours possess hydration, emulsification, foaming, and gelation properties that may support their use as functional ingredients in different food systems. Their incorporation into cereal-based and gluten-free products has therefore attracted growing attention. Cakes, muffins, and cookies are particularly suitable for pulse flour incorporation because their multicomponent formulations permit substantial nutritional modification and partial or complete replacement of conventional cereal flours (Bravo-Núñez & Gómez, 2023). However, the successful use of pulse flours depends on their composition and techno-functional properties, which may vary according to pulse species and cultivar, seed fraction, particle size, and processing conditions (Alfaro-Diaz et al., 2023; Romano et al., 2021).
Pulse flours are generally produced by milling whole or dehulled dry seeds. Whole-seed flours retain the seed coat and therefore contain the fiber, phenolic compounds, and natural pigments concentrated in this anatomical fraction. However, retaining the seed coat may result in a darker flour and a more pronounced effect on the color and flavor of the final product. Dehulling changes flour composition by removing at least part of the fiber- and phytochemical-rich seed coat. Particle size also influences flour functionality because milling changes the surface area available for interactions with water and other food components. Furthermore, soaking, cooking, roasting, germination, fermentation, extrusion, and other treatments can be applied before drying and milling. These processes modify the structural and functional characteristics of proteins and starch and thereby influence water and oil absorption, pasting, gelation, and the behavior of the flour in a food matrix.

Pulse flour production should therefore be regarded not merely as a size-reduction operation but as a process that determines the nutritional, technological, and sensory properties of the resulting ingredient (Alfaro-Diaz et al., 2023; Carboni et al., 2024; Ma et al., 2011).

Lentil (*Lens culinaris Medik*.) is an important source of plant protein and complex carbohydrates. Depending on genetic and environmental factors, lentil seeds contain approximately 21–31% protein and 62–69% total carbohydrates, with starch accounting for about 35–53% of seed weight. Lentils also provide dietary fiber, minerals, vitamins, and phytochemicals. Their proteins contain all essential amino acids and are particularly rich in lysine, although sulfur-containing amino acids such as methionine and cysteine are limiting. This amino acid profile provides a nutritional rationale for combining lentil ingredients with cereals, which may complement the amino acid composition of pulses (Romano et al., 2021). Lentil flour is produced by milling whole or dehulled seeds and can also be fractionated into protein- and starch-rich ingredients. Its water and oil absorption, solubility, emulsification, foaming, and gelation properties influence its technological behavior in food formulations. These properties are particularly relevant to batter viscosity, gas-cell formation and stability, crumb structure, and texture in bakery products.

The functionality of lentil flour is strongly influenced by the treatments applied before milling. Thermal processing can induce protein denaturation and starch gelatinization, thereby modifying water absorption, emulsification, foaming, and gelation properties. Ma et al. (2011) demonstrated that thermal processing altered the functional properties and microstructure of lentil, chickpea, and pea flours, although the effects differed according to pulse species and treatment conditions. Carboni et al. (2024) found that soaking and cooking increased the fiber content and water absorption capacity of lentil flour while decreasing its ash content and producing changes in color and particle-size distribution. Soaking, germination, and subsequent thermal treatments also altered the secondary structure and solubility of lentil proteins and improved their digestibility under the processing conditions examined by Najib et al. (2023). Therefore, raw and precooked lentil flours cannot be considered technologically equivalent, and findings obtained with untreated lentil flour cannot be directly generalized to precooked flour.

Common bean (Phaseolus vulgaris L.) flour is similarly obtained by milling whole or dehulled seeds. It contains protein, complex carbohydrates, slowly digestible and resistant starch fractions, dietary fiber, phenolic compounds, and other bioactive constituents. Proteins and starch are mainly concentrated in the cotyledons, whereas substantial proportions of fiber, phenolic compounds, and natural pigments are located in the seed coat. Consequently, the use of whole or dehulled beans influences both the nutritional composition of the flour and the color and flavor that it imparts to the final product. Protein solubility, water- and oil-binding capacity, gelation, foaming, and emulsification are among the principal techno-functional properties determining the behavior of common bean ingredients in food formulations (Alfaro-Diaz et al., 2023).

Dzudie and Hardy (1996) demonstrated that flours obtained from common beans and green mung beans differed in their physicochemical and functional properties. In particular, common bean flour exhibited higher water and oil absorption capacities than green mung bean flour. Although their study did not investigate bakery products or precooked flours, it provided early evidence that flours from different pulse species should not be expected to behave identically in food systems. Subsequent studies have shown that common bean flour functionality is also markedly affected by processing. Lin and Fernández-Fraguas (2020) reported that hydrothermal and high-hydrostatic-pressure treatments produced different changes in the pasting, rheological, thermal, and functional properties of common bean flours. Under their experimental conditions, prolonged hydrothermal treatment produced the highest elastic and viscous moduli and gel strength. Choe et al. (2022) found that moist-heat treatment increased the water-holding capacity and in vitro starch and protein digestibility of common bean flours, whereas dry-heat treatment increased oil-holding capacity and modified the flavor profile. Roasting conditions have likewise been shown to alter the proximate composition and functional properties of common bean flour (Byarugaba et al., 2023). These findings confirm that the technological performance of common bean flour depends not only on bean type but also on the nature and intensity of the treatment applied before milling.

The incorporation of lentil and common bean flours into cereal and bakery products can improve nutritional composition but may also alter batter behavior and product quality.

Gülhan and Karaça (2023) reported that incorporating 10–30% lentil flour into gluten-free muffins increased protein content. However, lentil flour addition reduced batter pH and specific volume, increased batter density, intensified crumb yellowness and browning, and modified textural properties. Similarly, Geraldo et al. (2024) found that partially replacing oatmeal flour with green lentil flour in muffins increased protein and dietary fiber contents and decreased fat content. These findings demonstrate the nutritional contribution of lentil flour while also showing that its effects on batter aeration, volume, color, and texture depend on the flour level and the accompanying ingredients.

Common bean flour has also been evaluated in muffin and other cereal-based formulations. Contini et al. (2022) completely replaced whole-wheat flour with blends of wholemeal rye and common black bean flours. Among the tested cereal–bean formulations, the muffin containing 70% rye flour and 30% bean flour exhibited the highest acceptability and was characterized by relatively low hardness, chewiness, and gumminess and high cohesiveness. Nevertheless, this result reflects the combined contribution of rye and bean flours rather than the independent performance of common bean flour. Moreover, the nutritional advantages of common bean flour do not necessarily ensure equivalent sensory acceptance. Sparvoli et al. (2021) reported that food products containing biofortified, lectin-free common bean flour had nutritional advantages but were generally less appreciated than the corresponding reference products without bean flour. Thus, the incorporation level, pretreatment, and interactions between bean flour and other formulation components must be considered together.

Replacing wheat flour with pulse flours also presents a structural challenge. In wheat-based bakery systems, gluten proteins contribute to the formation and stabilization of air and gas cells during mixing and baking. Partial substitution dilutes this structure, whereas complete replacement removes the gluten network and requires proteins, starches, fibers, lipids, and other ingredients to maintain sufficient batter viscosity and gas-cell stability. As a result, pulse flour incorporation may affect batter density, expansion, product volume, crumb porosity, hardness, springiness, cohesiveness, and chewiness. Complete replacement may nevertheless be feasible in appropriately designed formulations. Raeva et al. (2024) reported that mung bean flour could completely replace wheat flour in a sponge-cake formulation without producing an unacceptable product in terms of physical and sensory characteristics. Acun (2026) also showed that germinated and ungerminated mung bean flours used as partial or complete replacements for rice flour enhanced the nutritional and bioactive properties of gluten-free cakes, although physical and textural quality remained dependent on formulation. These studies support the potential of pulse flours but cannot be directly extrapolated to muffins prepared with precooked lentil and common bean flour blends.

Despite growing research on pulse flour functionality and its use in bakery products, information on the combined use of precooked yellow lentil and common bean flours in muffins remains limited. Previous studies have generally investigated a single pulse species, raw or differently processed flours, partial cereal flour substitution, or pulse–cereal flour combinations. Therefore, it has not been clearly established how systematically varying the ratio of precooked yellow lentil and common bean flours affects batter and muffin quality when these blends completely replace wheat flour. Since lentil and common bean flours differ in composition, hydration properties, response to thermal processing, color, and contribution to texture, their blending ratio may determine the balance between nutritional improvement and technological quality. Accordingly, this study aimed to evaluate the effects of different blending ratios of precooked yellow lentil and common bean flours, used as complete replacements for wheat flour, on batter properties and the chemical, physical, color, and textural characteristics of muffins.

MATERIAL AND METHODS

Materials

Precooked yellow lentil flour and precooked common bean flour were supplied by Kenton (Türkiye). Cake flour, granulated sugar, pasteurized whole egg, margarine, skimmed milk powder, baking powder, and salt used in muffin production were purchased from local markets. All chemicals and reagents used in the analyses were of analytical grade.

Characterization of precooked pulse flours

The moisture and ash contents of the precooked yellow lentil and common bean flours were determined gravimetrically according to Cemeroğlu (2007). The color characteristics of the flour samples were measured using a colorimeter following the procedure described by Larrosa et al. (2016), and the results were expressed in terms of the CIE L^*, a^*, and b^*coordinates. In this color system, L^*indicates lightness, whereas $a^*$and b^*represent the red–green and yellow–blue axes, respectively. The bulk and tapped bulk densities of the precooked pulse flours were determined according to Mutlu and Erbaş (2018). All measurements were performed in triplicate, and the results were expressed as mean ± standard deviation.

Experimental design and muffin formulations

A wheat-flour control and five pulse-based formulations were prepared. Wheat flour was completely replaced in all pulse-based formulations, and only the proportion of precooked yellow lentil flour to precooked common bean flour was varied. The total amount of flour was standardized to 100 g in every formulation. The quantities of all remaining ingredients were kept constant to isolate the effect of the lentil-to-bean flour ratio.

Table 1. Formulations of muffins prepared with different ratios of precooked yellow lentil and common bean flours

Ingredient (g)	Control	L0B100	L25B75	L50B50	L75B25	L100B0
Wheat flour	100	0	0	0	0	0
Precooked yellow lentil flour	0	0	25	50	75	100
Precooked common bean flour	0	100	75	50	25	0
Granulated sugar	40	40	40	40	40	40
Whole egg	60	60	60	60	60	60
Margarine	42	42	42	42	42	42
Distilled water	35	35	35	35	35	35
Skimmed milk powder	7.5	7.5	7.5	7.5	7.5	7.5
Baking powder	3	3	3	3	3	3
Salt	0.5	0.5	0.5	0.5	0.5	0.5

Control: muffin prepared with 100% wheat flour; L0B100: 0% lentil flour and 100% common bean flour; L25B75: 25% lentil flour and 75% common bean flour; L50B50: 50% lentil flour and 50% common bean flour; L75B25: 75% lentil flour and 25% common bean flour; L100B0: 100% lentil flour and 0% common bean flour.

Muffin production

Muffins were produced using the procedure reported by Acun (2026), with the flour composition adjusted according to the experimental design. Pasteurized whole egg was initially mixed for 1.5 min at speed 1 using a hand mixer (Tefal Smart, Türkiye). Distilled water was then added, and mixing was continued for 1 min. After the addition of sugar, the mixture was beaten for another minute. Margarine was subsequently incorporated and mixed for an additional minute at the same speed.

The flour, skimmed milk powder, baking powder, and salt were combined separately and then added to the liquid mixture. The batter was mixed at speed 1 for 1 min, followed by 30 s at speed 2, until a uniform consistency was obtained. Portions of 35 g batter were transferred into paper baking cups placed in 12-cavity metal muffin trays. Baking was performed on the middle rack of a three-level Siemens countertop oven at 210 °C for 20 min.

After baking, the muffins were retained in the trays for 20 min. They were then removed from the molds and cooled at room temperature for a further 40 min before analysis.

Batter properties

Batter pH and density were determined before baking. The pH was measured directly in the batter using a calibrated digital pH meter. Batter density was determined according to Masoodi et al. (2002) by filling a container of known volume with batter and calculating the mass-to-volume ratio. The results were expressed as g/mL.

Chemical composition of muffins

Moisture and ash contents were determined according to AACC Methods 44-01.01 and 08-01.01, respectively (AACC, 2000). Protein content was measured using the Dumas combustion method with a Gerhardt nitrogen–protein analyzer (Germany). Chemical analyses were performed in triplicate, and the results were expressed as percentages.

Physical properties of muffins

The physical properties of the muffins were evaluated by determining volume, density, symmetry index, uniformity index, total volume index, upper shrinkage, lower shrinkage, and baking loss. Dimensional characteristics were measured using a modified cake-measuring template based on the procedures described by AACC (2000), Bath et al. (1992), and Dizlek and Gül (2009).

Muffin volume was determined by the rapeseed displacement method (Acun, 2026). After cooling to room temperature, each muffin was weighed, and muffin density was calculated as the ratio of muffin mass to volume:

$$\text{Muffin density (g/mL)} = \frac{\text{Muffin mass (g)}}{\text{Muffin volume (mL)}}$$

Baking loss was calculated from the difference between the batter weight before baking and the muffin weight after cooling:

$$\text{Baking loss (\%)} = \frac{\text{Batter weight before baking} - \text{Muffin weight after cooling}}{\text{Batter weight before baking}} \times 100$$

Color measurement

The crust and crumb color characteristics of the muffins were measured using a PCE CSM 8 spectrocolorimeter (PCE Instruments, Germany). Measurements were expressed according to the CIE $L^*a^*b^*$color system, in which L^*represents lightness on a scale from black to white, positive and negative a^*values indicate redness and greenness, respectively, and positive and negative b^*values indicate yellowness and blueness, respectively.

Crust color was measured directly on the external surface of the muffins. For crumb color measurement, the muffins were cut horizontally, and readings were obtained from the central crumb region. Three measurements were performed for each formulation.

Chroma (C^*), hue angle ($h°$), and total color difference (ΔE^*) were calculated separately for the crust and crumb using the following equations:

$$C^* = \sqrt{a^{*2} + b^{*2}}$$

$$h° = \text{atan2}(b^*, a^*) \times \frac{180}{\pi}$$

$$\Delta E^* = \sqrt{\left(L^*_{\text{sample}} - L^*_{\text{control}}\right)^2 + \left(a^*_{\text{sample}} - a^*_{\text{control}}\right)^2 + \left(b^*_{\text{sample}} - b^*_{\text{control}}\right)^2}$$

The mean L^*, a^*, and b^*coordinates of the wheat-flour control were used as the reference values in the calculation of ΔE^*. Accordingly, the ΔE^*value of the control was defined as zero. The derived C^*, $h°$, and ΔE^*values were calculated for each replicate before statistical analysis. Results were expressed as mean ± standard deviation.

Texture profile analysis

The textural properties of the muffins were evaluated using a TA.XT Plus texture analyzer (Stable Micro Systems, Surrey, UK) fitted with a 5 kg load cell and a 36 mm cylindrical probe. Before analysis, the muffins were cut horizontally with an electric knife, and the upper crust was removed. Measurements were conducted on the crumb section located within 4 cm of the muffin base.

A two-cycle compression test was applied, with the crumb compressed to 50% of its original height. Pre-test, test, and post-test speeds were each set to 1.0 mm/s. The resulting force–time curves were used to determine hardness, springiness, cohesiveness, gumminess, chewiness, and resilience. Texture measurements were performed in triplicate.

Sensory Evaluation

The sensory properties of the muffin samples were evaluated by a semi-trained panel consisting of 10 students and staff members from the Food Technology Program, aged 20–32 years, using a procedure adapted from Ataman and Gül (2020). Before the evaluation, the panelists were informed about the sensory attributes and scoring criteria. Randomly coded muffin samples were presented individually, and cold drinking water was provided between samples to cleanse the palate.

The samples were evaluated for crust color, crumb color, pore structure, texture by touch, chewiness, disintegration in the mouth, absence of dryness/grittiness, odor, aroma, taste/flavor, and overall acceptability using a five-point sensory scale. The scale was defined as follows: 5 = very good, 4 = good, 3 = acceptable, 2 = insufficient, and 1 = poor.

Statistical Analysis

The results were expressed as mean ± standard deviation. Differences between precooked common bean and yellow lentil flours were evaluated using a two-tailed independent-samples t-test. Differences among the control and pulse-based muffin formulations were analyzed by one-way analysis of variance (ANOVA). When a significant formulation effect was detected, the means were compared using Duncan's multiple-range test. Statistical significance was accepted at $p < 0.05$. All statistical analyses were performed using SPSS Statistics, version 26.0 (IBM Corp., Armonk, NY, USA).

RESULTS AND DISCUSSIONS

Physicochemical Properties of Precooked Pulse Flours

The physicochemical properties of the precooked common bean and yellow lentil flours are presented in Table 2. The moisture contents of the flours did not differ significantly ($p > 0.05$). In contrast, common bean flour had a significantly higher ash content than yellow lentil flour ($p < 0.05$). Choe et al. (2022) reported ash contents of 3.87–4.19% in raw flours obtained from different common bean classes and showed that moist- and dry-heat treatments affected these values differently. Carboni et al. (2024) reported ash contents of 3.3% and 1.8% in raw and soaked–cooked lentil flours, respectively. When the literature findings and the present results are considered together, the ash content of pulse flours appears to vary depending on the combined effects of pulse species and processing conditions.

All instrumental color parameters differed significantly between the flours ($p < 0.05$). Yellow lentil flour had higher $L^*$and b^*values, indicating a lighter and more yellow appearance, whereas common bean flour had a higher a^*value. Carboni et al. (2024) similarly demonstrated that thermal treatment and particle size significantly affected the L^*, a^*, and b^*values of lentil flours. Alfaro-Diaz et al. (2023) noted that retaining the seed coat, particularly in dark-colored common bean cultivars, may influence the appearance of the resulting flour and food product. The observed color differences were considered to result from the combined effects of the inherent pigment composition of the raw materials and processing-related characteristics.

Table 2. Physicochemical properties of precooked common bean and yellow lentil flours

	Precooked common bean flour	Precooked yellow lentil flour
Moisture (%)	9.75 ± 0.72[a]	9.25 ± 0.72[a]
Ash (%)	4.00 ± 0.29[a]	2.50 ± 0.17[b]
L^*	74.00 ± 2.31[b]	83.00 ± 1.73[a]
a^*	3.75 ± 0.72[a]	1.75 ± 0.43[b]
b^*	17.00 ± 1.73[b]	23.00 ± 1.73[a]
Bulk density (g/mL)	0.63 ± 0.04[a]	0.56 ± 0.03[a]
Tapped bulk density (g/mL)	0.80 ± 0.06[a]	0.72 ± 0.05[a]

Values are presented as mean ± standard deviation. Control: muffins prepared with 100% wheat flour; L0B100: 0% yellow lentil flour and 100% common bean flour;

L25B75: 25% yellow lentil flour and 75% common bean flour; L50B50: 50% yellow lentil flour and 50% common bean flour; L75B25: 75% yellow lentil flour and 25% common bean flour; L100B0: 100% yellow lentil flour and 0% common bean flour. Means followed by different lowercase superscript letters within the same column are significantly different ($p < 0.05$).

Common bean flour exhibited numerically higher bulk and tapped bulk density values than yellow lentil flour, but the differences were not significant ($p > 0.05$). Therefore, the two flours showed comparable packing properties under the conditions applied. Overall, the precooked common bean and yellow lentil flours differed mainly in ash content and color, while their moisture and density characteristics were statistically similar.

Batter Properties

The pH and density values of the muffin batters are presented in Table 3. Both parameters were significantly affected by flour formulation ($p < 0.05$). Batter pH increased progressively from 6.76 in the wheat-flour control to 7.07 in L100B0 as the proportion of yellow lentil flour increased. The L0B100 batter had a pH of 6.83, which was closer to the control. These results demonstrate that the lentil-to-bean flour ratio systematically affected the acid–base characteristics of the batter. Gülhan and Karaça (2023) reported pH values of 6.92–7.13 for wheat-containing and gluten-free muffin batters formulated with different levels of lentil flour. Although their formulation and substitution design differed from those of the present study, the pH values were within a comparable range.

Table 3. pH and density values of muffin batters prepared with different ratios of precooked yellow lentil and common bean flours

	pH	Batter density (g/mL)
Control	6.76±0.02^{f}	1.10±0.00^{b}
L0B100	6.83±0.01^{e}	1.13±0.00^{a}
L25B75	6.89±0.02^{d}	1.05±0.00^{c}
L50B50	6.95±0.01^{c}	1.01±0.00^{d}
L75B25	7.01±0.05^{b}	0.99±0.00^{e}
L100B0	7.07±0.02^{a}	0.96±0.00^{f}

Values are presented as mean ± standard deviation. Control: muffins prepared with 100% wheat flour; L0B100: 0% yellow lentil flour and 100% common bean flour; L25B75: 25% yellow lentil flour and 75% common bean flour; L50B50: 50% yellow lentil flour and 50% common bean flour; L75B25: 75% yellow lentil flour and 25% common bean flour; L100B0: 100% yellow lentil flour and 0% common bean flour. Means followed by different lowercase superscript letters within the same column are significantly different ($p < 0.05$).

Batter density was highest in L0B100 (1.13 g/mL) and decreased progressively as the proportion of lentil flour increased, reaching its lowest value in L100B0 (0.96 g/mL). The control batter had a density of 1.10 g/mL. Thus, replacing common bean flour with increasing proportions of lentil flour improved air incorporation during mixing, as lower batter density generally indicates a greater amount of entrapped air. Gülhan and Karaça (2023) also found that flour composition significantly affected muffin batter density, reporting values between 0.79 and 1.04 g/mL for wheat-containing and gluten-free formulations. In their study, lentil flour addition to the gluten-free formulation increased batter density, demonstrating that the effect of lentil flour depends on the composition of the flour blend and the surrounding batter system.

Chemical Composition of Muffins

The moisture, ash, and protein contents of the muffins produced using different ratios of precooked yellow lentil and common bean flours are presented in Table 4. The formulation had a statistically significant effect on ash and protein contents ($p < 0.05$), whereas no significant difference was observed among the samples in terms of moisture content ($p > 0.05$).

Table 4. Moisture, ash, and protein contents of muffins produced with different ratios of precooked yellow lentil and common bean flours

	Moisture (%)	Ash (%)	Protein (%)
Control	16.66±0.72[a]	1.13±0.00[e]	7.56±0.05[e]
L0B100	18.83±3.29[a]	2.34±0.04[a]	21.36±1.19[d]
L25B75	17.72±2.92[a]	2.04±0.01[b]	22.90±0.11[c]
L50B50	16.28±2.16[a]	1.84±0.01[c]	23.90±0.16[b]
L75B25	15.01±1.43[a]	1.75±0.03[d]	24.83±0.21[a]
L100B0	14.51±2.70[a]	1.72±0.00[d]	25.57±0.06[a]

Values are presented as mean ± standard deviation. Control: muffins prepared with 100% wheat flour; L0B100: 0% yellow lentil flour and 100% common bean flour; L25B75: 25% yellow lentil flour and 75% common bean flour; L50B50: 50% yellow lentil flour and 50% common bean flour; L75B25: 75% yellow lentil flour and 25% common bean flour; L100B0: 100% yellow lentil flour and 0% common bean flour. Means followed by different lowercase superscript letters within the same column are significantly different ($p < 0.05$).

The moisture contents of the muffins ranged from 14.51% to 18.83%. Although the highest numerical value was recorded for L0B100 and the lowest for L100B0, all samples were included in the same statistical group. Therefore, the numerical decrease observed with increasing lentil flour proportion should be considered only as a trend and cannot be attributed to a statistically significant formulation effect. Gülhan and Karaça (2023) reported that the moisture contents of lentil flour-enriched muffins ranged from 15.58% to 17.02%, with the formulation containing the highest lentil flour level exhibiting the lowest moisture content. In the present study, the absence of a significant difference among the pulse-based formulations indicates that moisture retention after baking may depend not only on flour type but also on the overall formulation and baking conditions. Similarly, Gularte et al. (2012) found no significant differences in the moisture contents of gluten-free cakes prepared with different pulse flours. The control muffin had an ash content of 1.13%, whereas the use of pulse flours increased the ash content to 1.72–2.34%. This corresponded to an increase of approximately 52–107% compared with the control. Among the pulse-based formulations, the highest ash content was recorded for L0B100, which was produced entirely with common bean flour. Ash content decreased progressively as yellow lentil flour replaced common bean flour, reaching 1.72% in L100B0. This pattern was consistent with the composition of the raw materials: the ash contents of the precooked common bean and yellow lentil flours were 4.00% and 2.50%, respectively. Therefore, the variation in muffin ash content can be attributed to the different ash contents of the two pulse flours used in the formulations. Similarly, Gülhan and Karaça (2023) reported that increasing the lentil flour level increased the ash content of muffins from 1.12% to 1.30%. Gularte et al. (2012) also reported ash contents of 1.7% for the control cake and 2.0% and 2.2% for cakes containing lentil and common bean flours, respectively. These findings support the increase in ash content observed following the replacement of wheat flour with pulse flours.

All pulse-based formulations had significantly higher protein contents than the wheat flour control ($p < 0.05$). The protein content was 7.56% in the control and ranged from 21.36% to 25.57% in the pulse-based muffins. Thus, the complete replacement of wheat flour with pulse flours increased the protein content by approximately 2.8–3.4-fold relative to the control. Among the pulse-based formulations, protein content increased progressively with increasing yellow lentil flour proportion. The lowest value was recorded for L0B100, containing 100% common bean flour, whereas the highest value was obtained for L100B0, containing 100% yellow lentil flour. However, the difference between L75B25 and L100B0 was not statistically significant.

The increase in protein content was consistent with previous studies conducted on muffin and cake systems.

Gülhan and Karaça (2023) reported that increasing the lentil flour level from 10% to 30% increased the protein content of gluten-free muffins from 5.21% to 6.58%. Geraldo et al. (2024) determined a protein content of 8.10% in green lentil flour muffins, representing a 47% increase compared with the 5.50% protein content of the oatmeal-based control. Gularte et al. (2012) reported that the protein content increased from 6.2% in the control cake to 9.1% and 9.4% in cakes containing lentil and common bean flours, respectively. Carboni et al. (2024) also found that gluten-free cakes produced entirely with lentil flour contained 16.04% protein on a dry matter basis and had a markedly higher protein content than formulations without lentil flour. Differences in absolute protein values among studies may be associated with variations in flour composition, replacement level, other formulation ingredients, and whether the results were expressed on a wet or dry matter basis. Nevertheless, these studies consistently demonstrate that the use of pulse flours increases the protein content of baked products.

Overall, the complete replacement of wheat flour with precooked yellow lentil and common bean flours did not significantly affect the moisture content of the muffins but resulted in marked increases in their ash and protein contents. Common bean flour was more effective in increasing ash content, whereas yellow lentil flour provided the greatest increase in protein content.

Physical Properties of Muffins

The physical properties of muffins produced using different ratios of precooked yellow lentil and common bean flours are presented in Table 5. The formulation had a statistically significant effect on the symmetry index, total volume index, baking loss, and muffin volume ($p < 0.05$). In contrast, the uniformity index and upper and lower shrinkage values were not significantly affected by the formulation ($p > 0.05$).

Table 5. Physical properties of muffins produced with different ratios of precooked yellow lentil and common bean flours

	Control	L0B100	L25B75	L50B50	L75B25	L100B0
Symmetry index (mm)	13.00 ± 1.00^{ab}	3.67 ± 0.98^{bc}	4.00 ± 3.00^{bc}	12.68 ± 0.75^{ab}	−3.67 ± 2.08^{c}	21.68 ± 3.21^{a}
Uniformity index (mm)	−1.00 ± 1.00^{a}	0.33 ± 1.52^{a}	0.00 ± 2.64^{a}	0.67 ± 1.15^{a}	−0.33 ± 0.58^{a}	−0.33 ± 2.51^{a}
Upper shrinkage (mm)	7.00 ± 2.00^{a}	14.67 ± 6.65^{a}	11.00 ± 2.00^{a}	13.33 ± 1.15^{a}	9.67 ± 2.51^{a}	14.33 ± 0.57^{a}
Lower shrinkage (mm)	4.00 ± 0.20^{a}	6.00 ± 0.25^{a}	5.67 ± 2.08^{a}	4.33 ± 2.08^{a}	3.67 ± 1.15^{a}	6.33 ± 1.53^{a}
Total volume index (mm)	265.67 ± 1.53^{a}	244.67 ± 1.47^{c}	247.00 ± 3.46^{c}	251.00 ± 0.96^{bc}	264.67 ± 4.04^{ab}	237.00 ± 4.58^{c}
Baking loss (%)	12.78 ± 1.08^{a}	11.07 ± 0.66^{b}	10.41 ± 0.85^{b}	11.13 ± 0.53^{b}	10.36 ± 0.43^{b}	10.49 ± 1.04^{b}
Muffin volume (mL)	65.00 ± 2.00^{a}	33.67 ± 1.05^{b}	24.67 ± 0.57^{bc}	25.67 ± 3.51^{bc}	25.33 ± 0.58^{bc}	22.67 ± 2.39^{c}
Specific volume (mL/g)	2.11±0.08^{a}	1.07±0.34^{b}	0.77±0.01^{c}	0.82±0.12^{bc}	0.80±0.01^{bc}	0.71±0.07^{c}
Cake density (g/mL)	0.48±0.02^{c}	0.99±0.30^{b}	1.29±0.02^{a}	1.24±0.18^{ab}	1.25±0.02^{ab}	1.41±0.15^{a}

Values are presented as mean ± standard deviation. Control: muffins prepared with 100% wheat flour; L0B100: 0% yellow lentil flour and 100% common bean flour; L25B75: 25% yellow lentil flour and 75% common bean flour; L50B50: 50% yellow lentil flour and 50% common bean flour; L75B25: 75% yellow lentil flour and 25% common bean flour; L100B0: 100% yellow lentil flour and 0% common bean flour. Means followed by different lowercase superscript letters within the same row are significantly different ($p < 0.05$).

The symmetry index ranged from −3.67 to 21.68 mm. The lowest symmetry index was recorded for L75B25, whereas the highest value was obtained for L100B0. However, L100B0 was statistically similar to the control and L50B50 samples. The symmetry index represents the difference in height between the central and lateral regions of a muffin. Positive values indicate that the central region is higher than the edges, whereas negative values indicate that the central height is lower than the lateral regions (de la Hera et al., 2012). Accordingly, the high positive symmetry index of L100B0 indicates a more pronounced elevation in the central region. In contrast, the negative value recorded for L75B25 indicates that its central height remained below the lateral regions. Because the symmetry index does not directly represent total product volume, a high symmetry index should not be interpreted alone as an indication of improved volume development.

The uniformity index ranged from −1.00 to 0.67 mm, and all samples were included in the same statistical group ($p > 0.05$). Uniformity index values close to zero indicate a limited difference in height between the two sides of the muffins. Therefore, the use of different ratios of yellow lentil and common bean flours instead of wheat flour did not significantly change the distribution of height between the muffin edges. Similarly, Gülhan and Karaça (2023) reported that the uniformity index of lentil flour-enriched muffins was not significantly affected by the formulation.

Upper shrinkage values ranged from 7.00 to 14.67 mm, whereas lower shrinkage values ranged from 3.67 to 6.33 mm. Although numerical differences were observed among the samples, the formulation had no significant effect on either upper or lower shrinkage ($p > 0.05$). Accordingly, varying the blending ratio of yellow lentil and common bean flours did not significantly alter the dimensional contraction of the muffins during baking and cooling. Gularte et al. (2012) similarly reported that the collapse values of gluten-free cakes prepared with different pulse flours were generally not significantly affected by pulse flour incorporation, except for the formulation containing pea flour.

The total volume index ranged from 237.00 to 265.67 mm. The control exhibited the highest value, whereas L75B25 had the closest value to the control at 264.67 mm and was statistically similar to it. In contrast, the total volume indices of L0B100, L25B75, and L100B0 were significantly lower than that of the control. The lowest total volume index was recorded for L100B0. Gülhan and Karaça (2023) also reported that the volume indices of lentil flour-enriched muffins were lower than that of the wheat flour control. de la Hera et al. (2012) demonstrated that the effect of lentil flour on cake volume may vary depending on the cake system, inclusion level, lentil cultivar, and flour particle size. In the present study, the statistical similarity between L75B25 and the control in terms of total volume index indicates that the total height across the muffin cross-section was maintained at this blending ratio. Nevertheless, because the displacement volume of L75B25 was significantly lower than that of the control, the total volume index and muffin volume should be evaluated together.

Baking loss was 12.78% in the control and ranged from 10.36% to 11.13% in the pulse-based formulations. All pulse-based muffins had significantly lower baking loss than the control but were statistically similar to one another. These findings demonstrate that the complete use of precooked yellow lentil and common bean flours instead of wheat flour reduced the mass lost during baking. Gülhan and Karaça (2023) reported baking loss values ranging from 14.8% to 17.1% for lentil flour-enriched muffins, with no significant differences among the formulations. The different findings obtained in the two studies may be associated with differences in flour characteristics, formulation ingredients, and baking conditions.

Significant differences were observed among the formulations in terms of muffin volume ($p < 0.05$). The control had the highest volume at 65.00 mL, whereas the volumes of the pulse-based muffins ranged from 22.67 to 33.67 mL. These values corresponded to an approximately 48.2–65.1% decrease in muffin volume compared with the control. Among the pulse-based formulations, L0B100 had the highest volume, whereas L100B0 had the lowest. No significant differences were observed among the volumes of L25B75, L50B50, and L75B25.

The decrease in volume may be associated with the absence of the viscoelastic structure provided by gluten following the complete removal of wheat flour and the resulting limited retention of expanding gas cells during baking. de la Hera et al. (2012) reported that the use of lentil flour could reduce cake volume and that a lower batter density did not necessarily result in a higher final product volume. Final cake volume may be affected not only by the amount of air incorporated into the batter but also by gas loss during baking, starch gelatinization, and thermally induced changes in proteins.

In the present study, muffin volume did not increase despite the reduction in batter density with increasing lentil flour proportion. This result indicates that incorporating more air during mixing alone was insufficient to ensure its retention throughout baking.

Overall, using precooked yellow lentil and common bean flours as complete alternatives to wheat flour reduced baking loss and did not significantly affect the uniformity index or upper and lower shrinkage values. However, all pulse-based formulations exhibited markedly lower muffin volumes than the control. Although L75B25 was statistically similar to the control in terms of total volume index, its muffin volume determined by the displacement method remained significantly lower. Therefore, cross-sectional indices and displacement volume should be considered together when evaluating the physical properties of pulse-based muffins.

Specific volume was significantly affected by the formulation ($p < 0.05$). The control had the highest specific volume at 2.11 mL/g, whereas the values of the pulse-based muffins ranged from 0.71 to 1.07 mL/g. Among the pulse-based formulations, L0B100 had the highest specific volume, while L100B0 had the lowest. The approximately 49.3–66.4% reduction relative to the control indicates that the pulse-based muffins developed less volume per unit mass. Gularte et al. (2012) reported that lentil and common bean flours increased the specific volume of rice flour-based gluten-free cakes, whereas de la Hera et al. (2012) demonstrated that the effect of lentil flour on cake volume depended on the cake system, lentil cultivar, and flour particle size. Therefore, the effect of pulse flours on specific volume may vary according to the base flour system and formulation characteristics.

Muffin density changed inversely to specific volume, increasing from 0.48 g/mL in the control to 0.99–1.41 g/mL in the pulse-based formulations ($p < 0.05$). Among the pulse-based muffins, L0B100 had the lowest density, whereas L100B0 had the highest. The combination of the lowest volume and specific volume with the highest density in L100B0 indicates the formation of a more compact product structure as the proportion of yellow lentil flour increased. de la Hera et al. (2012) similarly reported that reduced volume was accompanied by increased density in some lentil flour-containing cake formulations. These findings demonstrate that using precooked pulse flours as complete alternatives to wheat flour decreased muffin volume and specific volume while increasing product density.

Color Properties of Muffins

The crust and crumb color properties of muffins produced using different ratios of precooked yellow lentil and common bean flours are presented in Table 6. The formulation had a statistically significant effect on the L*, a*, b*, C*, hue angle, and ΔE values of both the crust and crumb ($p < 0.05$).

The control had the highest crust L* value at 55.09, whereas the values of the pulse-based muffins ranged from 38.07 to 41.65. This result demonstrates that the complete use of precooked pulse flours instead of wheat flour produced a darker muffin crust. Among the pulse-based formulations, L75B25 had the highest L* value, whereas L25B75 had the lowest. However, L0B100, L50B50, and L100B0 shared statistical groups with these formulations. As also observed in Figure 1, the control had a lighter and more uniformly colored surface, whereas the pulse-based muffins exhibited darker crusts with a less uniform color distribution.

The crust a* value decreased from 20.27 in the control to 13.29–16.48 in the pulse-based muffins. The control had a significantly higher a* value than all pulse-based formulations, whereas no significant differences were observed among the pulse-based muffins. Thus, the use of pulse flours reduced the redness component of the crust. The control also had the highest crust b* value at 38.62. Among the pulse-based formulations, L75B25 had the highest b* value, whereas L0B100 and L25B75 had the lowest values. These findings indicate that the control crust had stronger red and yellow color components than the crusts of the pulse-based muffins.

The crust C* value, which represents color saturation, was 43.62 in the control and decreased to 24.15–29.99 in the pulse-based formulations. Among these formulations, L75B25 had the highest C* value, whereas L0B100 and L25B75 had the lowest values. Therefore, the use of pulse flours reduced crust color saturation. The crust hue angle was also significantly higher in the control (62.31°) than in the pulse-based muffins, whose values ranged from 56.30° to 57.29°. No significant differences in crust hue angle were observed among the pulse-based formulations.

Crust ΔE values calculated relative to the control ranged from 19.47 to 25.56. The highest numerical color difference was recorded for L25B75, whereas L75B25 had the lowest ΔE value. The lower ΔE of

L75B25 indicates that its crust color was closer to that of the control than those of the other pulse-based formulations. Nevertheless, the high numerical ΔE values obtained for all pulse-based muffins demonstrate a marked difference from the control crust color.

Table 6. Crust and crumb color properties of muffins produced with different ratios of precooked yellow lentil and common bean flours

	Crust					
Sample	*L**	*a**	*b**	*C**	Hue°	ΔE
Control	55.09±0.67^{a}	20.27±1.03^{a}	38.62±1.43^{a}	43.62±1.69^{a}	62.31±0.64^{a}	0.00±0.00^{c}
L0B100	39.21±2.96^{bc}	13.29±2.05^{b}	20.14±3.47^{c}	24.15±3.85^{c}	56.50±2.95^{b}	25.40±4.53^{a}
L25B75	38.07±1.91^{c}	13.50±2.72^{b}	20.86±2.66^{c}	24.87±3.63^{c}	57.29±2.74^{b}	25.56±3.84^{a}
L50B50	39.99±1.37^{bc}	15.40±1.59^{b}	23.59±2.32^{bc}	28.18±2.74^{bc}	56.86±1.32^{b}	21.87±2.84^{ab}
L75B25	41.65±0.91^{b}	16.48±0.84^{b}	25.06±1.22^{b}	29.99±1.46^{b}	56.66±0.48^{b}	19.47±1.63^{b}
L100B0	39.19±1.23^{bc}	15.19±0.53^{b}	22.77±0.18^{bc}	27.38±0.40^{bc}	56.30±0.83^{b}	23.03±0.72^{ab}
	Crumb					
Control	77.21±0.72^{a}	0.58±0.14^{b}	30.77±0.33^{d}	30.78±0.56^{d}	88.91±0.24^{a}	0.00±0.00^{c}
L0B100	71.20±1.03^{b}	3.61±0.49^{a}	30.45±0.51^{d}	30.66±0.56^{d}	83.25±0.82^{c}	6.76±1.03^{b}
L25B75	72.22±1.66^{b}	3.69±0.84^{a}	35.42±0.54^{c}	35.61±0.54^{c}	84.04±1.35^{bc}	7.58±1.28^{b}
L50B50	72.43±2.69^{b}	3.31±0.91^{a}	36.61±1.07^{c}	36.77±0.97^{c}	84.80±0.58^{bc}	8.33±1.25^{b}
L75B25	72.17±0.30^{b}	3.52±0.13^{a}	40.06±0.43^{b}	40.21±0.44^{b}	84.98±0.14^{bc}	10.97±0.27^{a}
L100B0	71.75±1.23^{b}	3.43±0.50^{a}	41.49±1.17^{a}	41.64±1.13^{a}	85.26±0.80^{b}	12.44±0.43^{a}

Values are presented as mean ± standard deviation. Means followed by different lowercase superscript letters within the same column and within the same muffin region are significantly different ($p < 0.05$). ΔE values were calculated relative to the corresponding mean color values of the control crust or crumb.

The crumb L* value was 77.21 in the control and decreased to 71.20–72.43 in the pulse-based muffins. All pulse-based formulations had significantly lower L* values than the control but were statistically similar to one another. Therefore, using precooked yellow lentil and common bean flours instead of wheat flour resulted in a darker crumb. Gularte et al. (2012) similarly reported lower crumb L* values in gluten-free cakes containing lentil and common bean flours than in the control.

The crumb a* value increased from 0.58 in the control to 3.31–3.69 in the pulse-based formulations. All pulse-based muffins had significantly higher a* values than the control but were statistically similar to one another. This finding indicates that the use of pulse flours increased the redness component of the crumb. Gularte et al. (2012) also reported that common bean flour increased the crumb a* value and indicated that the effects of pulse flours on product color were related to the original colors of the flours.

The crumb b* value was 30.77 in the control. L0B100 had a comparable b* value of 30.45, whereas b* increased with increasing yellow lentil flour proportion and reached 41.49 in L100B0. L25B75 and L50B50 were statistically similar, while L75B25 and L100B0 had higher b* values. These results demonstrate that the yellowness of the crumb became more pronounced as the proportion of yellow lentil flour increased. This pattern was consistent with the raw material results, as precooked yellow lentil flour had a higher b* value than precooked common bean flour. Gülhan and Karaça (2023) similarly reported an increase in crumb b* with increasing lentil flour addition.

Crumb C* values followed a pattern similar to the b* values. The control and L0B100 were statistically similar, with C* values of 30.78 and 30.66, respectively. C* increased with increasing yellow lentil flour proportion and reached 41.64 in L100B0. Thus, increasing the proportion of yellow lentil flour enhanced crumb color saturation. The control had the highest crumb hue angle at 88.91°, whereas L0B100 had the lowest value at 83.25°. Although the hue angle generally increased as the yellow lentil flour proportion increased, all pulse-based formulations remained below the control.



Figure 1. Profile and cross-sectional views of muffins produced with different ratios of precooked yellow lentil and common bean flours.

The upper row shows the profile views, and the lower row shows the cross-sectional views. In both rows, the samples are arranged from left to right as Control, L0B100, L25B75, L50B50, L75B25, and L100B0.

Crumb ΔE increased from 6.76 in L0B100 to 12.44 in L100B0 as the proportion of yellow lentil flour increased. L0B100, L25B75, and L50B50 were statistically similar, whereas L75B25 and L100B0 exhibited the highest color differences. These findings indicate that the crumb color became increasingly different from the control as the proportion of yellow lentil flour increased. The cross-sectional views in Figure 1 also show differences between the crumb colors of the control and pulse-based muffins, with a more pronounced yellow appearance in the formulations containing higher proportions of yellow lentil flour.

Overall, the complete use of precooked yellow lentil and common bean flours instead of wheat flour resulted in darker muffin crusts and crumbs. In the crust, L*, a*, b*, and C* values decreased, whereas crumb L* decreased and a* increased. Increasing the yellow lentil flour proportion particularly increased crumb b* and C*, resulting in greater yellowness and color saturation. L75B25 had the lowest crust ΔE, whereas L0B100 had the lowest crumb ΔE. These results demonstrate that both pulse flour type and blending ratio were major determinants of muffin crust and crumb color.

Textural Properties of Muffins

The textural properties of the muffins are presented in Table 7. The formulation significantly affected hardness, springiness, cohesiveness, chewiness, and resilience ($p < 0.05$). The control exhibited the lowest hardness (949.68 g) and chewiness (450.67 g), together with the highest springiness (0.865), cohesiveness (0.549), and resilience (0.193). In contrast, hardness and chewiness increased to 4335.17–6126.74 g and 955.85–1616.19 g, respectively, in the pulse-based muffins, while springiness, cohesiveness, and resilience decreased. These changes indicate that using precooked pulse flours as complete alternatives to wheat flour resulted in a harder and more compact crumb with a lower ability to recover after compression. This interpretation is also consistent with the lower specific volume and higher density of the pulse-based muffins.

Table 7. Textural properties of muffins produced with different ratios of precooked yellow lentil and common bean flours

Sample	Hardness (g)	Springiness	Cohesiveness	Chewiness (g)	Resilience
Control	949.68 ± 2.90^{d}	0.865 ± 0.01^{a}	0.549 ± 0.02^{a}	450.67 ± 7.63^{c}	0.193 ± 0.01^{a}
L0B100	5981.17 ± 6.15^{a}	0.529 ± 0.01^{c}	0.301 ± 0.00^{d}	955.85 ± 1.23^{b}	0.104 ± 0.00^{d}

L25B75	6126.74 ± 4.30^{a}	0.588 ± 0.02^{c}	0.372 ± 0.03^{c}	1339.86 ± 1.07^{ab}	0.133 ± 0.01^{c}
L50B50	5413.46 ± 7.13^{ab}	0.714 ± 0.06^{b}	0.396 ± 0.08^{bc}	1553.50 ± 5.03^{a}	0.146 ± 0.03^{bc}
L75B25	4762.04 ± 5.62^{bc}	0.739 ± 0.05^{b}	0.457 ± 0.02^{b}	1616.19 ± 3.14^{a}	0.165 ± 0.00^{b}
L100B0	4335.17 ± 1.80^{c}	0.763 ± 0.05^{b}	0.442 ± 0.01^{bc}	1464.71 ± 156^{a}	0.160 ± 0.00^{bc}

Values are presented as mean ± standard deviation. Control: muffins prepared with 100% wheat flour; L0B100: 0% yellow lentil flour and 100% common bean flour; L25B75: 25% yellow lentil flour and 75% common bean flour; L50B50: 50% yellow lentil flour and 50% common bean flour; L75B25: 75% yellow lentil flour and 25% common bean flour; L100B0: 100% yellow lentil flour and 0% common bean flour. Means followed by different lowercase superscript letters within the same column are significantly different ($p < 0.05$).

Among the pulse-based formulations, L0B100 had the lowest springiness, cohesiveness, and resilience values. Hardness reached its highest level in L25B75 and then progressively decreased as the proportion of yellow lentil flour increased. Conversely, springiness, cohesiveness, and resilience generally increased with increasing yellow lentil flour proportion. Thus, yellow lentil flour partially moderated the textural changes observed in the common bean-rich formulations. Nevertheless, none of the pulse-based muffins achieved the softness or structural recovery characteristics of the wheat flour control.

Chewiness followed a slightly different pattern, increasing from 955.85 g in L0B100 to its highest value of 1616.19 g in L75B25 and then decreasing numerically in L100B0. The higher chewiness of all pulse-based muffins indicates that more energy would be required to break down their crumb during mastication compared with the control. The simultaneous increase in hardness and chewiness, together with reductions in springiness and resilience, confirms that the absence of the wheat-based structure substantially altered crumb texture.

de la Hera et al. (2012) similarly reported that lentil flour could increase cake hardness and reduce springiness and cohesiveness. Gülhan and Karaça (2023) also observed formulation-dependent reductions in the springiness and cohesiveness of lentil flour-enriched muffins. Gularte et al. (2012) found increased hardness and chewiness in gluten-free cakes containing common bean flour, whereas the textural changes caused by lentil flour were more limited. Taken together, these findings indicate that the textural effects of pulse flours depend on the pulse type and blending ratio, as well as the composition of the base formulation.

Sensory Evaluation

The mean sensory scores of the muffin samples are presented in Figure 2. The control received the highest scores for all attributes except odor and was particularly distinguished by its crust color (3.9), crumb color (4.0), chewiness (3.7), and mouthfeel (3.9). Although the crumb color and pore structure scores of most pulse-based muffins remained at acceptable levels, lower scores were obtained for texture- and flavor-related attributes. These findings were consistent with the higher hardness and density and lower springiness and cohesiveness determined instrumentally in the pulse-based muffins.

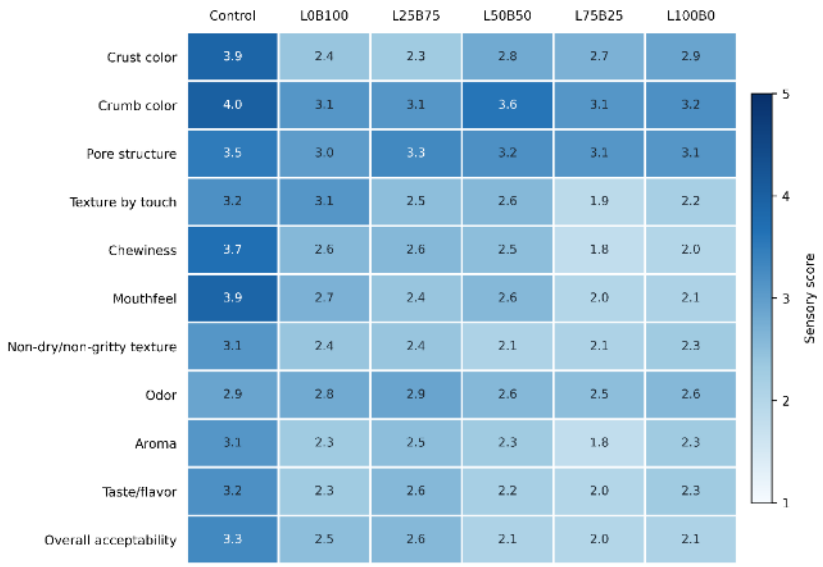


Figure 2. Heatmap of the sensory scores of muffins produced with different ratios of precooked yellow lentil and common bean flours. Scores were evaluated using a five-point scale, where 1 represented poor and 5 represented very good. Higher sensory scores are indicated by darker colors.

Among the pulse-based formulations, L25B75 received the highest or joint-highest scores for pore structure (3.3), aroma (2.5), taste/flavor (2.6), and overall acceptability (2.6). L50B50 had the highest crumb color score among the pulse-based muffins (3.6), whereas L0B100 was evaluated more favorably for texture by touch (3.1), chewiness (2.6), and mouthfeel (2.7). In contrast, L75B25 received the lowest scores for texture by touch, chewiness, and aroma. Although some color and flavor scores increased in L100B0 compared with L75B25, its overall acceptability remained at 2.1. This distribution indicates that the sensory effects of yellow lentil and common bean flours were not linear and that their blending ratio was an important determinant of sensory quality.

Gülhan and Karaça (2023) reported that the overall acceptability of muffins containing up to 30% lentil flour could remain comparable to that of the controls. Carboni et al. (2024) found that although cakes containing 100% lentil flour were technologically feasible, consumers preferred a formulation combining lentil and rice flours. In the present study, the complete use of pulse flours instead of wheat flour reduced the scores for texture, mouthfeel, taste/flavor, and overall acceptability. Nevertheless, the highest overall acceptability of L25B75 among the pulse-based formulations suggests that blending yellow lentil and common bean flours may provide a more balanced sensory profile than using either pulse flour alone. Because the individual panelist data were not subjected to statistical analysis, numerical differences among the samples were interpreted descriptively.

CONCLUSION

This study demonstrated that the complete replacement of wheat flour with precooked yellow lentil and common bean flours was technically feasible in muffin production and substantially improved nutritional composition. Pulse-based muffins contained approximately 2.8–3.4 times more protein than the control, while common bean flour contributed more strongly to ash content and yellow lentil flour progressively increased protein content. Moisture content was not significantly affected, and all pulse-based formulations exhibited lower baking loss than the control.

Despite these nutritional advantages, complete wheat flour replacement caused marked technological changes. Pulse-based muffins had lower volume and specific volume and higher density, hardness, and chewiness, together with reduced springiness, cohesiveness, and resilience. Their crusts and crumbs were also darker than those of the control, while increasing the yellow lentil flour proportion enhanced crumb yellowness and color saturation. The blending ratio significantly influenced product quality: L0B100 provided the highest volume and specific volume among the pulse-based formulations, whereas increasing the yellow lentil flour proportion generally reduced hardness and partially improved springiness, cohesiveness, and resilience.

Sensory evaluation confirmed the technological findings, as the control received the highest scores for most attributes. Among the pulse-based muffins, L25B75 showed the highest overall acceptability and comparatively favorable scores for pore structure, aroma, and taste/flavor, suggesting that blending the two pulse flours produced a more balanced sensory profile than using either flour alone. However, no formulation simultaneously matched the control in nutritional, physical, textural, color, and sensory properties. Overall, precooked yellow lentil and common bean flours offer promising ingredients for developing wheat flour-free, protein-enriched muffins, but further formulation optimization is required to improve gas retention, crumb softness, mouthfeel, and sensory acceptance while maintaining the nutritional benefits.

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A COMPARATIVE ANALYSIS OF PASTA PRODUCTION, CONSUMPTION, AND TRADE PATTERNS WITH A FOCUS ON TÜRKİYE

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ABSTRACT
This study provides a comprehensive analysis of global and national trends in pasta production, consumption, foreign trade, and pricing, with a particular focus on Türkiye and major pasta-producing countries. Utilising data from FAOSTAT, TÜİK, TRADEMAP, and the International Pasta Organisation, the research identifies a consistent upward trajectory in worldwide pasta production, consumption, and trade volumes. Italy and Türkiye emerge as leading producers and exporters, with over half of their pasta production destined for international markets. The research highlights Türkiye's rapid growth in production and export capacity, rising from 14th to 2nd place in global pasta export volume between 2001 and 2025. Price analyses reveal that despite rising global pasta prices, Türkiye maintains lower export prices than other major producers, with higher price volatility. The research also details market diversification trends, showing Türkiye's expanding export reach, especially into African and Asian markets. Comparative evaluations of other key exporters such as Italy, China, South Korea, and Thailand underscore varying competitiveness and trade balances. The findings underscore the importance of raw material accessibility, technological advancement, and strategic market expansion in sustaining competitiveness. The study concludes that the growth in production and trade significantly influences global pasta prices and that Türkiye's pasta sector holds a strategic position in the agricultural-based industrial landscape, with a notable export surplus and competitive advantages.
Keywords: pasta industry; pasta production; international trade; export; Price analyses

INTRODUCTION
Grains have served as fundamental components of the human diet since ancient times, with wheat being the most extensively cultivated and produced grain in Türkiye, mirroring global trends (Özkan and Gül, 2024). Wheat's versatility as a raw material is especially critical in the production of staple foods such as bread, semolina, bulgur, and pasta. Particularly in economically developed societies with high levels of prosperity, the decrease in people's physical activity on the one hand, and the widespread use of refined foods with low dietary fibre content on the other, have increased the incidence of certain diseases such as cardiovascular diseases, digestive system diseases, obesity, diabetes, and intestinal diseases. Therefore, studies on the metabolic importance and health benefits of dietary fibre are intensifying (Gül, 2007).
Over the next decade, the total consumption of agricultural products is expected to increase by 12.5%. This increase will be driven almost entirely by middle- and low-income countries, where population growth expands aggregate demand, and rising incomes and rapid urbanisation reshape consumption patterns (OECD/FAO, 2026). Although Türkiye is a significant wheat importer, it processes imported wheat in agricultural industries (flour and pasta) and exports it. Although imported wheat is used in agricultural industries, the decrease in wheat cultivation areas and the increase in Türkiye's foreign trade deficit over the years are important issues that need to be addressed (Kadakoğlu et al., 2024).
The Turkish Food Codex Pasta Regulation stipulates that pasta is produced by hydrating semolina sourced from Triticum durum wheat, subsequently undergoing kneading, shaping, and drying using specified techniques. Pasta products are classified as plain, whole wheat, flavoured, enriched, fortified, and those with added vitamins and minerals (RG, 2002). The origins and global spread of pasta have been interpreted in various ways in the literature (Acun and Gül, 2023).

In Türkiye, the transition to factory production of pasta began in 1922 with the establishment of the first pasta production facility in the Bayraklı district of İzmir. From 1960 onwards, small-scale production facilities were replaced by larger and higher-capacity pasta factories. With this transformation, production capacity increased significantly, as did the number of factories in operation, and the sector gained a more institutionalised and industrialised structure (Palacıoğlu and Emil 2004; Haboğlu 2007). The Turkish pasta industry has reached a level where it can compete with technologically advanced countries, not only meeting domestic demand but also catering to international demand. The pasta industry operates 22 factories with a combined installed capacity exceeding 1 million tonnes. One of the main challenges facing the sector is the difficulty in obtaining raw materials. Agricultural policies must address this issue by implementing contract farming. To enhance the sector's competitiveness, emphasis should be placed on, and support should be given to, the modernisation of operations, RandD studies, export support, and market research (Karlı et al., 2015).

Having reached a strategic position among Türkiye's agricultural-based industrial sectors, pasta production has achieved significant export potential thanks to its strong domestic production capacity and competitiveness in foreign markets. This study aims to analyse the trends and dynamics of pasta production, consumption, foreign trade, and pricing in Türkiye, contextualised within the global landscape and compared with other leading pasta-producing countries.

MATERIALS AND METHODS

The main material of this study consists of data from FAOSTAT, the Turkish Statistical Institute (TÜİK), TRADEMAP, and the International Pasta Organization report. The study also utilises research from the national and international literature on the subject. Pasta export prices were analysed for relevant stakeholders. In this context, the general trend of the price series was determined using the simple average method and the coefficients of variation. Thus, changes and developments in prices over the years were identified, and their causes were explored in this study. The coefficient of variation and price volatility were calculated to measure changes in pasta prices. Price volatility, using the standard deviation, determines price fluctuations over a specific period (Acar and Gül, 2022).

RESULTS AND DISCUSSIONS

World pasta production

According to data from the International Pasta Organization (IPO), global pasta production, which was approximately 10.5 million tons in 2005, increased to 13 million tons in 2010, 15 million tons in 2015, and 15.8 million tons in 2020, and is projected to reach 17.6 million tons in 2025, representing a 67% increase. Italy is the world's largest pasta producer with 4.2 million tons and a 23.7% share. Türkiye has risen to second place with over 2 million tons of production.

Pasta production is now possible in many countries worldwide, owing to technological advancements. Pasta production, once limited to wheat-producing regions, has spread to diverse geographies. Countries such as Italy, Türkiye, the USA, Egypt, Brazil, Russia, Nigeria, Iran, Germany, and Mexico account for a large majority of the world’s production. Countries such as Italy, Türkiye, and Egypt produce for export in addition to meeting domestic consumption needs. However, other countries produce to meet their domestic demand.

Pasta production is predominantly concentrated in Europe, with Italy holding a significant share of global output, accounting for 29.0% in 2005 and an anticipated 23.7% by 2025, reflecting a 37% increase in production over this period. Türkiye's share of world pasta production was 4.9% in 2005 and is expected to rise to 11.9% by 2025. During this period, it increased its pasta production by 4.07 times. The United States maintained a relatively stable share, rising slightly from 11.1% in 2005 to 11.4% in 2025, with production growing by 72%. Egypt demonstrated substantial growth, tripling its share from 3.8% to 6.8% between 2005 and 2025. Conversely, Brazil's share declined from 9.5% to 6.6%, despite a 15% increase in production volume.

Russia’s share decreased from 8.2% in 2005 to 5.8% in 2025, though production increased by 18%. Nigeria’s share slightly declined from 4.2% in 2021 to 4.0% in 2025. Similarly, Iran’s share fell from 4.3% in 2010 to 3.2% in 2025. Germany’s share decreased marginally from 2.5% to 2.3%, with a 59% rise in production. Mexico’s share also declined slightly from 2.4% to 2.3%, accompanied by a 58% increase in output.

Spain's share of world pasta production was 2.4% in 2005 and is expected to rise to 2.2% in 2025. During this period, pasta production increased by 58%. Peru's share decreased from 2.2% to 2.0%, representing a 59% increase in production. Tunisia's share increased from 1.1% in 2005 to 2.0% in 2025, representing a 3.05-fold increase. Argentina's share remained stable at 1.5%, with a 66% rise in production. France's share decreased from 2.3% in 2005 to 1.4% in 2025, representing a 2% decrease, while Venezuela's share dropped significantly from 3.1% to 1.2%, a 37% reduction.
Poland's share decreased from 1.4% to 0.8%, with a 3% decline in production. Chile maintained a stable share of 1.2%, increasing production by 68%. Greece's share slightly decreased from 1.4% to 1.1%, with a 32% increase in output. Japan's share declined from 1.4% to 0.8%, and Canada's share fell from 1.6% to 0.8%, with a 20% reduction in production. Colombia's share decreased from 1.1% to 0.7%, while its production tripled during the period.

World pasta trade

World pasta imports averaged approximately 2.94 million tons between 2001 and 2004, but increased 2.53 times to exceed 7.44 million tons by 2025. The largest pasta importer in the world is the USA, with 746,628 tons. Pasta imports increased by 99% compared to the base year. In 2025, the USA will have the largest share of global pasta imports, at 10.27%. The USA's share of pasta imports was 13.21% during the 2001-2004 period (Table 1).

Table 1. The amount of pasta imports (TRADEMAP, 2026)

	2001-2004	2005-2009	2010-2014	2015-2019	2020-2024	2025
	Quantity (tonnes)					
USA	385197	390952	403227	469500	656413	764628
Germany	370759	456668	498764	539969	616867	748938
France	289975	361046	400214	458463	526517	580537
United Kingdom	231442	327443	377805	378543	483426	520797
Netherlands	65972	86756	141215	167105	226974	261133
Japan	161963	168563	184927	193107	233529	258830
Canada	140931	170769	197556	204120	240011	254340
China	12171	12729	30809	92655	153934	210353
Belgium	71577	80517	119980	164268	186138	204366
Poland	18281	49607	64083	76869	112555	177952
Hong Kong	99358	112726	139500	158854	166841	161517
Australia	62428	79218	95239	110672	140053	149524
Republic of Korea	64860	78672	95748	114927	138860	147120
Spain	40410	53723	40951	87461	90763	145874
Malaysia	28015	47239	79011	94877	120368	133123
Austria	37810	55664	63299	74891	102343	131348
Togo	8017	10547	20866	43468	68452	103773
Others	847264	1316815	2635452	2424026	2562376	2487527
Total	2936430	3859655	5588646	5853776	6826421	7441682
	Share (%)					
USA	13.12	10.13	7.22	8.02	9.62	10.27
Germany	12.63	11.83	8.92	9.22	9.04	10.06
France	9.88	9.35	7.16	7.83	7.71	7.80
United Kingdom	7.88	8.48	6.76	6.47	7.08	7.00
Netherlands	2.25	2.25	2.53	2.85	3.32	3.51
Japan	5.52	4.37	3.31	3.30	3.42	3.48
Canada	4.80	4.42	3.53	3.49	3.52	3.42
China	0.41	0.33	0.55	1.58	2.25	2.83
Belgium	2.44	2.09	2.15	2.81	2.73	2.75
Poland	0.62	1.29	1.15	1.31	1.65	2.39

Hong Kong, China	3.38	2.92	2.50	2.71	2.44	2.17
Australia	2.13	2.05	1.70	1.89	2.05	2.01
Republic of Korea	2.21	2.04	1.71	1.96	2.03	1.98
Spain	1.38	1.39	0.73	1.49	1.33	1.96
Malaysia	0.95	1.22	1.41	1.62	1.76	1.79
Austria	1.29	1.44	1.13	1.28	1.50	1.77
Togo	0.27	0.27	0.37	0.74	1.00	1.39
Others	28.85	34.12	47.16	41.41	37.54	33.43
Total	100.00	100.00	100.00	100.00	100.00	100.00

The leading countries in world pasta imports are Germany (748,938 tons), France (580,537 tons), the United Kingdom (520,797 tons), the Netherlands (261,133 tons), Japan (258,830 tons), Canada (254,340 tons), China (210,353 tons), Belgium (204,366 tons), and Poland (177,952 tons). Türkiye ranks 81st in terms of world pasta imports. In 2005, Türkiye's pasta import volume was 9,053 tons. Türkiye's average pasta import volume during the 2001-2004 period was 437 tons. Türkiye's pasta import volume increased to 6,200 tons during the 2020-2024 period and entered an upward trend. Globally, all countries examined showed a twofold or greater increase in pasta imports (Table 1).

Global pasta import values amounted to approximately $3.06 billion between 2001 and 2004. This value is projected to increase 5.1 times to approximately USD 15.63 billion by 2025. In 2025, the USA has the highest pasta import value, at approximately $2 billion. At the beginning of the period, the USA's pasta import value was approximately $427 million. The USA's pasta import value has consistently shown an upward trend. Germany's pasta import value increased from approximately $353 million at the beginning of the period to approximately $1.6 billion in 2025. In 2025, the USA's pasta import value was approximately $1.2 billion, and France's was approximately $1.16 billion. The global pasta import value has increased over the past few years. In major pasta-importing countries, import values have more than tripled compared to the base period. This increase influenced global pasta prices (Table 2). In 2025, the USA had the largest share of world pasta import value, with 12.35%. Germany follows this, with 10.06%; the United Kingdom, with 7.75%; France, with 7.41%; the Netherlands, with 4.55%; Canada, with 4.50%; China, with 3.77%; Japan, with 3.21%; Belgium, with 2.99%; Spain, with 2.74%; and Poland, with 2.42%. Türkiye's pasta import value, which was $870,000 in the 2001-2004 period, has increased to $22.36 million in 2025. Türkiye has risen to 66th place in the world in terms of pasta import value (Table 2).

Table 2. The value of pasta imports (TRADEMAP, 2026)

	2001-2004	2005-2009	2010-2014	2015-2019	2020-2024	2025
	Value (USD Thousand)					
USA	427014	613983	809886	949343	1567849	1929979
Germany	353054	620007	741558	767683	1123364	1572306
United Kingdom	251668	457443	551033	572287	991533	1211788
France	271014	512596	625968	661745	963223	1158914
Netherlands	93930	152873	248205	313487	540075	711886
Canada	182204	272777	389837	397692	590313	702976
China	10274	17554	62438	214203	378737	589928
Japan	233222	304249	349843	318916	437078	501807
Belgium	112373	179990	203967	220863	336292	468018
Spain	85324	129521	154490	193604	298110	427958
Poland	15528	58642	90192	115565	184968	378926
Australia	66861	122767	172927	211952	320462	356579
Austria	54733	99245	125724	142101	236147	347106
Hong Kong	106822	132389	232186	307413	342817	341398
Malaysia	20538	43017	114773	140705	210610	252409
Republic of Korea	44445	73965	124589	154578	225256	251932
Switzerland	48257	82463	120254	140178	196889	228346

Others	686712	1521462	3138843	2857777	4058906	4200207
Total	3063970	5394945	8256712	8680091	13002627	15632463
	Share (%)					
USA	13.94	11.38	9.81	10.94	12.06	12.35
Germany	11.52	11.49	8.98	8.84	8.64	10.06
United Kingdom	8.21	8.48	6.67	6.59	7.63	7.75
France	8.85	9.50	7.58	7.62	7.41	7.41
Netherlands	3.07	2.83	3.01	3.61	4.15	4.55
Canada	5.95	5.06	4.72	4.58	4.54	4.50
China	0.34	0.33	0.76	2.47	2.91	3.77
Japan	7.61	5.64	4.24	3.67	3.36	3.21
Belgium	3.67	3.34	2.47	2.54	2.59	2.99
Spain	2.78	2.40	1.87	2.23	2.29	2.74
Poland	0.51	1.09	1.09	1.33	1.42	2.42
Australia	2.18	2.28	2.09	2.44	2.46	2.28
Austria	1.79	1.84	1.52	1.64	1.82	2.22
Hong Kong	3.49	2.45	2.81	3.54	2.64	2.18
Malaysia	0.67	0.80	1.39	1.62	1.62	1.61
Republic of Korea	1.45	1.37	1.51	1.78	1.73	1.61
Switzerland	1.57	1.53	1.46	1.61	1.51	1.46
Others	22.41	28.20	38.02	32.92	31.22	26.87
Total	100.00	100.00	100.00	100.00	100.00	100.00

World pasta exports totalled approximately 3.2 million tons between 2001 and 2004. By 2025, this is expected to increase 2.7 times, reaching approximately 8.69 million tons. Italy is the leading country in world pasta exports. Italian pasta exports totalled approximately 1.56 million tons between 2001 and 2004. By 2025, this will increase by 68%, reaching approximately 2.62 million tons. With recent changes, Türkiye's pasta exports have increased 21 times from approximately 70 million tons in 2001-2004 to approximately 1.44 million tons by 2025. Similar rapid growth has been observed in the Republic of Korea, Indonesia, Thailand, Saudi Arabia, China, the USA, and Germany. Compared to the base year, pasta exports increased in all the countries considered. In 2025, Italy held the largest share of world pasta exports, at 30.13%. Türkiye follows this, with 16.54%; China, with 8.93%; the Republic of Korea, with 5.31%; Indonesia, with 2.85%; Thailand, with 2.73%; the USA, with 2.52%; Saudi Arabia, with 2.50%; Germany, with 2.38%; Belgium, with 2.07%; Spain, with 1.74%; and the Netherlands, with 1.52%. Türkiye rose from 14th place in world pasta export volume in 2001 to 2nd place in 2025 (Table 3).

Table 3. The amount of pasta exports (TRADEMAP, 2026)

	2001-2004	2005-2009	2010-2014	2015-2019	2020-2024	2025
	Quantity (tonnes)					
Italy	1562256	1743125	1933484	2086131	2440584	2617288
Türkiye	69567	184703	527091	1007912	1393361	1436656
China	316957	416988	489859	535362	644924	776044
Republic of Korea	76259	61558	88299	157885	311681	461070
Indonesia	38312	81291	123274	142683	204020	247702
Thailand	53762	89123	140311	182872	239104	237423
USA	134475	153302	199478	185439	213791	218945
Saudi Arabia	5806	27920	67883	74003	156619	217493
Germany	34749	66196	93888	126367	171046	206715
Belgium	107263	122374	141289	170213	182569	179374
Spain	48011	41673	61217	120095	152511	151276
Netherlands	23644	34371	49287	73623	99579	131821
Egypt	835	11226	60139	60472	69192	101985
France	81066	82889	103687	111232	103875	98720

Morocco	2931	5822	16084	33347	69381	97227
Czech Republic	19568	30849	39692	40888	59729	89081
Austria	15057	35568	50937	65670	82706	82521
Others	622394	944541	1331046	1495657	1814124	1334635
Total	3212911	4133521	5516949	6669849	8408797	8685976
	Share (%)					
Italy	48.62	42.17	35.05	31.28	29.02	30.13
Türkiye	2.17	4.47	9.55	15.11	16.57	16.54
China	9.87	10.09	8.88	8.03	7.67	8.93
Republic of Korea	2.37	1.49	1.60	2.37	3.71	5.31
Indonesia	1.19	1.97	2.23	2.14	2.43	2.85
Thailand	1.67	2.16	2.54	2.74	2.84	2.73
USA	4.19	3.71	3.62	2.78	2.54	2.52
Saudi Arabia	0.18	0.68	1.23	1.11	1.86	2.50
Germany	1.08	1.60	1.70	1.89	2.03	2.38
Belgium	3.34	2.96	2.56	2.55	2.17	2.07
Spain	1.49	1.01	1.11	1.80	1.81	1.74
Netherlands	0.74	0.83	0.89	1.10	1.18	1.52
Egypt	0.03	0.27	1.09	0.91	0.82	1.17
France	2.52	2.01	1.88	1.67	1.24	1.14
Morocco	0.09	0.14	0.29	0.50	0.83	1.12
Czech Republic	0.61	0.75	0.72	0.61	0.71	1.03
Austria	0.47	0.86	0.92	0.98	0.98	0.95
Others	19.37	22.85	24.13	22.42	21.57	15.37
Total	100.00	100.00	100.00	100.00	100.00	100.00

The value of world pasta exports in the 2001-2004 period was approximately $6.54 billion. This value increased 5.1 times by 2025, reaching approximately $16.6 billion. In 2025, Italy had the highest pasta export value, at approximately $4.83 billion (Table 4).

Table 4. The value of pasta exports (TRADEMAP, 2026)

	2001-2004	2005-2009	2010-2014	2015-2019	2020-2024	2025
	Value (USD Thousand)					
Italy	1293946	2222478	2734515	2767155	4105245	4833846
Republic of Korea	180570	188959	297419	484629	1066385	1755023
China	315295	507750	759262	874805	1154965	1398380
Türkiye	26429	117020	366216	498422	868984	911323
Thailand	70095	168595	354251	460414	663277	685670
Germany	63117	156414	214959	259495	417409	565563
Netherlands	44770	80400	152373	218077	365505	540965
USA	164444	247906	355913	354529	440628	498469
Indonesia	32587	84456	188025	228653	372660	473571
Belgium	172397	268541	303495	304274	398117	466765
Saudi Arabia	13569	45900	106834	122497	297045	424701
France	104434	165344	220448	215639	257382	306819
Austria	28440	96020	151720	177633	251536	292115
Spain	38018	59178	105517	136899	229472	269025
Poland	12939	22390	39812	80696	164570	198358
Hungary	6112	21137	36223	69937	155882	189831
Canada	108662	140824	175274	144756	157464	183926
Others	3864134	6824651	10277095	11563156	17341828	19198912
Total	3269978	5708981	8419677	9480833	14354177	16596631

	Share (%)					
Italy	39.57	38.93	32.48	29.19	28.60	29.13
Republic of Korea	5.52	3.31	3.53	5.11	7.43	10.57
China	9.64	8.89	9.02	9.23	8.05	8.43
Türkiye	0.81	2.05	4.35	5.26	6.05	5.49
Thailand	2.14	2.95	4.21	4.86	4.62	4.13
Germany	1.93	2.74	2.55	2.74	2.91	3.41
Netherlands	1.37	1.41	1.81	2.30	2.55	3.26
USA	5.03	4.34	4.23	3.74	3.07	3.00
Indonesia	1.00	1.48	2.23	2.41	2.60	2.85
Belgium	5.27	4.70	3.60	3.21	2.77	2.81
Saudi Arabia	0.41	0.80	1.27	1.29	2.07	2.56
France	3.19	2.90	2.62	2.27	1.79	1.85
Austria	0.87	1.68	1.80	1.87	1.75	1.76
Spain	1.16	1.04	1.25	1.44	1.60	1.62
Poland	0.40	0.39	0.47	0.85	1.15	1.20
Hungary	0.19	0.37	0.43	0.74	1.09	1.14
Canada	3.32	2.47	2.08	1.53	1.10	1.11
Others	18.17	19.54	22.06	21.96	20.81	15.68
Total	100.00	100.00	100.00	100.00	100.00	100.00

At the beginning of the period, Italy's pasta export value was approximately $1.29 billion. Italy's pasta export values have consistently trended upward. Türkiye's pasta export value, which was approximately $26.4 million at the beginning of the period, increased 35 times to approximately $911 million by 2025 (Table 4). Compared to the base year, the quantity of world pasta exports increased by 2.7 times in 2025. Compared to the base year, the value of world pasta exports increased by 5.1 times in 2025. Therefore, it can be stated that, in addition to the increase in the volume of world pasta exports, the increase in pasta export prices has had a greater impact.

In major pasta-exporting countries, the largest increases in export value compared to the base period in 2025 occurred in Türkiye, Hungary, Saudi Arabia, Indonesia, Poland, and the Netherlands. Increases were observed in all the countries examined. This can be attributed to higher unit pasta export prices.

In 2025, the country with the largest share of world export value is Italy, with 29.13%. This is followed by the Republic of Korea (10.57%), China (8.43%), Türkiye (5.49%), Thailand (4.13%), Germany (3.41%), and the Netherlands (3.26%). Türkiye, which ranked 29th in world pasta export value in 2001, is expected to rise to 4th place in 2025 (Table 4).

The development of Türkiye's pasta exports

Türkiye's pasta export volume shows a general upward trend from 2001–2004 to 2025. When evaluated on a country basis, Ghana (11.54%), Somalia (11.26%), Togo (7.96%), Benin (7.07%), Japan (5.22%), Iraq (4.69%), Niger (4.20%), Cuba (2.57%), Cameroon (2.45%), Burkina Faso (2.42%), Nigeria (2.22%), Venezuela (2.01%), China (1.94%), and the USA (1.66%) are significant markets. During the period under review, Türkiye exported pasta to over 150 countries, thereby increasing its market diversification. Exports to African countries have been intensified. Germany, Romania, Ukraine, and Bulgaria are traditional European markets. Significant increases have been observed in countries such as Iraq and Japan, particularly after 2010, indicating market diversification (Table 5). Türkiye is a net exporter of pasta, with a surplus of 1.05 million tons in terms of the export-import quantity difference. In particular, after 2017, the foreign trade surplus in pasta exceeded 1 million tons.

Saraçoğlu and Köse (2000) determined the competitiveness of the pasta, biscuit, and flour industries in 16 countries, including Türkiye, using the Comparative Export Performance Index and Principal Component Analysis. They noted that in the 1990s, Russia and the USA were Türkiye's most important markets. They highlighted that the Russian Federation's share of Türkiye's total pasta exports increased from approximately 10% in 1992 to 82.5% in 1997 and 79.7% in 1998, respectively.

In contrast, a different change was observed in the USA, with its share of Türkiye's total pasta exports falling from 53.5% in 1992 to 1% by 1998. Turhan (2008) calculated the import penetration rate, specialisation coefficient, openness to foreign competition, export market share, and export/import ratio to determine competitiveness. She determined that the Turkish pasta sector has recovered and increased its competitiveness since 1999.

Karlı et al. (2022) presented the development of wheat production and trade in the world and in Türkiye, and determined the level of international competitiveness in wheat flour. They reported that Türkiye ranks second in the world in terms of wheat import quantity and fourth in terms of value and is the leading exporter of wheat flour. They stated that imported wheat is converted into flour and flour products, a large portion of which is exported to other countries. They determined that Türkiye exports 19.04% of the world's wheat flour in terms of value and 22.45% in terms of quantity, that Türkiye has a high competitive advantage in wheat flour exports, and that it is a net exporter in wheat flour foreign trade.

Bayav and Gül (2024) evaluated the global pasta sector and analysed the competitiveness of the main exporting countries. They calculated indices for the main pasta-exporting countries: Türkiye, Italy, China, South Korea, Thailand, Iran, the USA, Indonesia, Belgium, and Germany. The results show that, except for the USA, China, and Germany, these countries have a comparative advantage in pasta trade. They stated that increasing high-quality durum wheat production and seeking new markets are important for maintaining competitive advantage.

When examining the share of world and Turkish pasta exports within total pasta production, it is observed that in 2010, 37% of world pasta production was exported. In 2015, this rate increased to 39.4% globally, and in 2018, 2019, 2020, 2021, 2022, and 2023, these rates were 47.9%, 48.4%, 53.3%, 50.9%, 48.2%, and 47.9%, respectively. This is projected to reach 49.5% by 2025. This rate continues to increase globally, with half of the production being exported to other countries. In Türkiye, the share of pasta exports within the total pasta production is projected to be 69.3% by 2025. In Türkiye, this rate varied between 3.4% and 71.9% from 1990 to 2025, with an average of 37.2% during these years. This rate reached its highest value in Türkiye in 2021 (71.9%) and its lowest value in 2002 (3.4%). It has levelled off since then. Especially after 2010, Türkiye became a country that exports more than half of its pasta production (Figure 1).

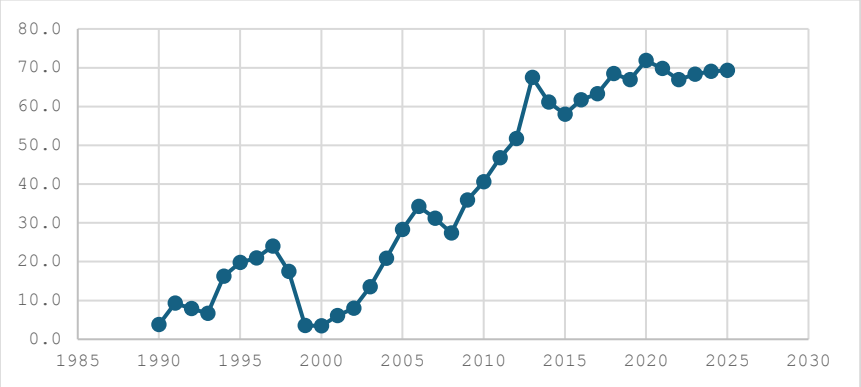


Figure 1. Turkish pasta export share in production (%)

Table 5. The amount of pasta that Türkiye exports to the countries (TRADEMAP, 2026)

	2001-2004	2005-2009	2010-2014	2015-2019	2020-2024	2025
	Amount (tonnes)					
Ghana	467	4334	6863	45908	93344	165740
Somalia	665	3144	12063	100358	192793	161736
Togo	249	10134	33850	60566	81427	114405
Benin	203	6717	55479	117831	79903	101523
Japan	1482	6162	21825	47300	61212	74927
Iraq	3539	16851	37974	60807	53692	67387
Niger	574	6472	19587	16920	48361	60277

Cuba	0	0	0	0	4426	36930
Cameroon	1469	4466	14500	16204	22976	35189
Burkina Faso	130	488	967	3092	13151	34818
Nigeria	369	403	655	4663	4538	31874
Venezuela	0	1040	6871	43600	184403	28946
China	13	298	2591	5289	19062	27926
USA	2841	2292	2300	8902	25547	23780
Canada	80	252	1620	12515	16976	21599
Chad	9	228	698	5998	17170	20799
Senegal	501	1596	2936	18892	32018	19785
Congo	0	220	2270	11394	18884	18994
Congo	273	4377	17230	14115	18076	18259
Colombia	0	0	522	1173	36	16830
Tanzania	33	2040	8966	7282	17690	16394
Côte d'Ivoire	9	118	3024	3480	10740	15160
Malaysia	8	172	1374	5848	13176	15002
Guinea	44	810	1919	3812	7683	14951
Others	56616	112094	271006	391962	356075	293423
Total	69570	184707	527090	1007911	1393360	1436654

Türkiye's pasta export value shows a significant upward trend from the 2001-2004 period to 2025. When evaluated on a country basis, Ghana (10.86%), Somalia (10.86%), Togo (7.96%), Benin (7.07%), Japan (5.22%), Iraq (4.69%), Niger (4.20%), Cuba (2.57%), Cameroon (2.45%), Burkina Faso (2.42%), Nigeria (2.22%), Venezuela (2.01%), China (1.94%), and the USA (1.66%) are important markets. During the period under review, Türkiye increased its market diversification. Exports to African countries have intensified. Germany, Romania, Ukraine, and Bulgaria are traditional European markets. Significant increases have been observed in countries such as Iraq and Japan, particularly after 2010, indicating market diversification. Türkiye has a surplus of $602 million in terms of pasta export-import values. In particular, after 2007, the foreign trade surplus in pasta exceeded $150 million.

The development of Italy's pasta exports

Italy is the world's leading pasta producer. Production is expected to increase by approximately 37% between 2005 and 2025, exceeding 4 million tons. The rising demand in foreign markets largely supported this increase. The share of global pasta exports in total pasta production is projected to increase to 49.5% by 2025. Therefore, half of the world's pasta production is exported. Italy's share of pasta exports in total pasta production is projected to be 62.8% by 2025. This share increased from 55.7% in 2005 to 56% in 2010 and 64.9% in 2021. Thus, Italy exports more than half of its pasta production to other countries.

Italy's pasta exports increased by 68% from approximately 1.57 million tons in 2001-2004 to approximately 2.62 million tons in 2025. Italy exports pasta to over 175 countries. Its main export market is the European Union, which accounts for nearly half of the market share. Other significant markets include Germany (18.56%), the USA (13.02%), France (12.47%), the United Kingdom (11.24%), Spain (3.29%), the Netherlands (2.84%), Japan (2.61%), Sweden (2.33%), Belgium (2.14%), Canada (1.75%), and Australia (1.68%). Italy is a net pasta exporter, with a surplus of approximately 1.92 million tons between its exports and imports (Table 6).

Table 6. The amount of pasta that Italy exports to the countries (TRADEMAP, 2026)

	2001-2004	2005-2009	2010-2014	2015-2019	2020-2024	2025
	Quantity (tonnes)					
Germany	333662	363389	367454	390342	430649	485732
USA	156129	146481	145740	188611	288254	340703
France	223274	255307	300808	274763	298704	326383
United Kingdom	184257	223610	257916	277089	305247	294251
Spain	24602	32935	33705	51367	72515	86081

Netherlands	39738	48909	51505	53440	67104	74346
Japan	78187	79272	84014	71340	73696	68327
Sweden	38296	44983	49053	54555	62642	61087
Belgium	26892	33788	42142	56567	60945	55921
Canada	22760	23801	24507	27541	37198	45799
Australia	19781	21659	25211	28543	37382	44025
Switzerland	26467	28813	31813	35402	45927	43634
Poland	8775	16309	21985	30529	38307	42840
Austria	27361	34542	36738	37495	40259	40257
Israel	15971	19012	23472	26985	31652	32327
Republic of Korea	9980	11667	16815	20535	28655	31753
Brazil	10559	11582	18459	21442	25386	30205
Others	315577	347067	402145	439585	496061	513614
Total	1562266	1743127	1933482	2086131	2440585	2617285

The value of Italian pasta exports increased 3.74 times from approximately $1.3 billion in the 2001–2004 period to approximately $4.84 billion by 2025. Important countries in Italy's export market include Germany (15.92%), the USA (15.53%), France (12.71%), the United Kingdom (10.65%), Spain (4.54%), the Netherlands (3.41%), Belgium (2.60%), Sweden (2.33%), Switzerland (2.12%), Canada (2.11%), Japan (2.04%), Australia (1.76%), and Austria (1.69%). Italy is a net pasta exporter with a trade surplus of $2.47 billion (Table 7).

Table 7. The value of pasta that Italy exports to the countries (TRADEMAP, 2026)

	2001-2004	2005-2009	2010-2014	2015-2019	2020-2024	2025
	Value (USD Thousand)					
Germany	251900	407534	467796	448851	644751	769625
USA	146244	212480	251116	329606	611582	750720
France	181987	319861	404536	385564	530113	614179
United Kingdom	163099	309953	368489	367872	481474	514701
Spain	41472	80457	83677	107460	166908	219314
Netherlands	34992	71211	79683	73218	119301	164604
Belgium	32268	55896	72784	82210	113774	125834
Sweden	30831	55145	71258	77860	102267	112543
Switzerland	32742	51553	66888	64536	97428	102301
Canada	20701	33974	43725	45574	79079	101872
Japan	69355	102729	115393	82576	98147	98382
Australia	15575	27738	37262	41732	70469	85289
Austria	23972	44206	53265	49281	72500	81466
Poland	6233	18197	28896	36266	58915	72674
Republic of Korea	8252	12878	19961	22273	39930	51135
Denmark	16200	29958	35795	31115	43201	50808
Brazil	7894	13513	26245	26400	38982	50727
Others	210232	375198	507744	494762	736422	867673
Total	1293948	2222480	2734512	2767157	4105243	4833847

The development of China's pasta exports

China's pasta export volume increased 2.45 times from 316,957 tons in the 2001–2004 period to 776,046 tons by 2025. China's main export markets are Asia (42%) and North America (25%). Important markets include Hong Kong (15.92%), USA (15.53%), Republic of Korea (12.71%), Canada (10.65%), Netherlands (4.54%), Japan (3.41%), United Kingdom (2.60%), Australia (2.33%), Russian Federation (2.12%), Germany (2.11%), Malaysia (2.04%), and the Philippines (1.76%). China has a trade deficit of 10,780 tons in pasta trade. The value of China's pasta exports increased 4.44 times from approximately $315 million in the 2001–2004 period to approximately $1.4 billion in 2025.

Important countries in China's export market include Hong Kong (14.18%), the USA (12.05%), the Republic of Korea (8.51%), Japan (7.86%), Canada (5.13%), the Netherlands (4.98%), the United Kingdom (4.33%), Australia (3.95%), the Russia (3.65%), Germany (3.16%), the Philippines (2.09%), Singapore (1.85%), Malaysia (1.83%), and France (1.77%). China has experienced a trade deficit of $3 million in pasta exports and imports over the past seven years.

The development of the Republic of Korea's pasta exports

Republic of Korea's pasta exports increased 6.1 times from 76,262 tons in 2001–2004 to 461,072 tons in 2025. China (25.05%) and the USA (22.43%) are the dominant export markets. Other important markets include Japan (7.58%), the Netherlands (5.01%), the Philippines (3.56%), Australia (3.48%), Canada (3.06%), the United Kingdom (3.01%), Malaysia (2.92%), Germany (2.68%), the Russian Federation (2.35%), and Thailand (2.35%). Republic of Korea has a pasta export-import deficit of 90,927 tons. The value of the Republic of Korea's pasta exports increased 9.72 times from approximately $181 million in 2001–2004 to approximately $1.76 billion in 2025. China (22.86%) and the USA (18.77%) are the dominant main export markets. Other significant markets include Japan (5.79%), the Netherlands (5.15%), the Philippines (3.85%), the United Kingdom (3.65%), Malaysia (3.37%), Australia (3.22%), Canada (2.86%), the Russian Federation (2.74%), Germany (2.60%), and Thailand (2.38%). Republic of Korea has a trade deficit of $99 million in pasta exports and imports.

The development of Thailand's pasta exports

Thailand's pasta export volume increased 4.42 times from 53,763 tons in the 2001-2004 period to 237,419 tons in 2025. Thailand's export markets have expanded from approximately 60 countries in the 2000s to 100 countries today. Important markets included the USA (13.42%), Lao People's Democratic Republic (9.55%), Myanmar (7.94%), Netherlands (7.47%), Malaysia (7.30%), Australia (6.01%), Canada (4.80%), Japan (4.54%), Cambodia (4.12%), France (4.01%), United Kingdom (3.58%), and the Republic of Korea (3.00%). Thailand is a net exporter of pasta, with a surplus of 70,743 tons compared to imports. Thailand's pasta export value increased 9.78 times from approximately $70 million in 2001–2004 to approximately $686 million in 2025. The important export markets for Thailand include the USA (15.00%), Lao People's Democratic Republic (9.04%), Australia (7.74%), Myanmar (7.64%), the Netherlands (7.17%), Japan (5.02%), Canada (4.73%), Cambodia (4.64%), France (4.59%), Malaysia (4.12%), the United Kingdom (3.63%), and the Republic of Korea (2.41%). Thailand has a trade surplus of $141 million in terms of export-import values for pasta.

The development of Germany's pasta exports

Germany's pasta export volume increased 5.95 times from 34,749 tons in the 2001-2004 period to 206,718 tons in 2025. Germany's main export market consists of European Union countries. France (17.91%), the United Kingdom (13.28%), Austria (12.18%), Poland (9.53%), the Netherlands (8.59%), Belgium (6.72%), the Czech Republic (4.28%), Switzerland (4.13%), Spain (2.58%), Hungary (2.35%), Sweden (2.16%), Denmark (2.14%), and Romania (2.05%) are significant markets. Germany has a pasta export-import deficit of 329,235 tons. The value of German pasta exports increased ninefold from approximately $63 million in 2001–2004 to approximately $566 million in 2025. Nearly 90% of Germany's exports are to European countries. Important markets include the Netherlands (13.15%), Austria (13.06%), France (12.91%), the United Kingdom (8.97%), Poland (8.43%), Switzerland (6.57%), Belgium (5.51%), Spain (4.01%), Czech Republic (3.93%), Sweden (2.92%), Italy (2.20%), and Denmark (2.06%). Germany is a net importer of pasta, with a trade deficit of approximately $390 million.

The development of the Netherlands' pasta exports

Netherlands pasta exports increased 6.5 times from 38,310 tons in 2001–2004 to 247,699 tons in 2025. Germany (31.61%) and Belgium (19.12%) are the main export markets for the Netherlands. Other important markets include France (9.75%), the United Kingdom (6.34%), Poland (4.97%), Spain (4.27%), and Denmark (3.28%). Germany and Belgium are the largest buyers, accounting for over 50% of exports. The Netherlands had a trade deficit of 77,341 tons. The value of the Netherlands' pasta exports increased 12.1 times from approximately $45 million in 2001–2004 to approximately $541 million in 2025.

Germany (27.67%) and Belgium (19.51%) constitute more than 50% of the Netherlands' export market. Other markets include France (10.23%), Poland (6.41%), the United Kingdom (5.45%), Denmark (4.52%), Spain (3.92%), Italy (3.34%), and Sweden (2.59%). Germany and Belgium are the largest buyers, accounting for over 50% of the export value. The Netherlands is a net importer of pasta, with a trade deficit of approximately $83 million.

The development of the USA's pasta exports

USA pasta exports increased by 63% from 134,476 tons in 2001–2004 to 218,649 tons by 2025. Canada (73.58%) is the main export market for USA pasta, followed by Mexico (8.71%) and Japan (6.46%). Canada is the largest buyer, resulting in a trade deficit of 315,887 tons. The value of USA pasta exports increased 3.3 times from approximately $165 million in 2001–2004 to approximately $499 million in 2025. Canada accounts for over 70% of USA pasta exports, followed by Mexico (9.53%), Japan (4.70%), Jamaica (1.92%), and the Bahamas (1.75%). Canada is the largest buyer, accounting for over 70% of export value. The USA is a net importer of pasta, with a trade deficit of approximately $597 million.

The development of Indonesia's pasta exports

Indonesian pasta exports increased 6.5 times from 38,310 tons in 2001–2004 to 247,699 tons in 2025. Malaysia is Indonesia's main export market (22.43%). Other significant markets include Cambodia (11.70%), China (9.44%), the Philippines (7.92%), Vietnam (6.36%), and Australia (4.97%). These countries are the largest buyers, accounting for over 50% of export volume. Indonesia has a surplus of 10,790 tons in pasta exports. The value of Indonesian pasta exports increased 14.53 times from approximately $33 million in 2001–2004 to approximately $474 million by 2025. Malaysia accounts for one-fifth of Indonesia's export market (19.74%). In addition, China (12.67%), Cambodia (9.92%), Australia (6.80%), Vietnam (5.14%) and the Philippines (4.57%) are the largest buyers, accounting for over 50% of the export value. Indonesia has a trade surplus of $11.2 million in terms of pasta export-import values.

The development of Belgium's pasta exports

Belgium's pasta export volume increased by 67% from 107,261 tons in 2001–2004 to 179,369 tons in 2025. Belgium's export market is dominated by the Netherlands (29.99%), the United Kingdom (21.46%), France (20.94%), and Germany (10.12%). These countries consistently account for more than 80% of the export volume. Belgium has a surplus of 22,500 tons in terms of export-import volume. The value of Belgium's pasta exports increased 2.7 times from approximately $173 million in 2001–2004 to approximately $467 million in 2025. Belgium's export market comprises the Netherlands (27.54%), France (20.24%), the United Kingdom (19.71%), and Germany (12.96%), which are the largest buyers in every period and account for over 80% of export value. Belgium has a surplus of $11 million in export-import values for pasta.

The development of Saudi Arabia's pasta exports

Saudi Arabia's pasta export volume increased 37.5 times from 5,806 tons in 2001–2004 to 217,495 tons by 2025. The Saudi Arabian export market is predominantly comprised of Middle Eastern countries. Iraq (51.37%), Yemen (12.67%), Sudan (6.60%), United Arab Emirates (6.40%), Jordan (6.18%), Kuwait (3.64%), State of Palestine (3.45%), and Lebanon (3.21%) are significant export markets. These countries consistently hold the position of largest buyers, accounting for over 50% of the export volume. Saudi Arabia has a surplus of 35,000 tons in pasta exports and imports, and has become a net exporter since the pandemic. The value of Saudi Arabia's pasta exports increased 31-fold from approximately $14 million in the 2001-2004 period to approximately $425 million in 2025. Important countries in Saudi Arabia's export market include Iraq (40.78%), Sudan (11.29%), Yemen (10.97%), the United Arab Emirates (9.95%), Jordan (6.83%), Kuwait (5.23%), Palestine (3.91%), Lebanon (2.86%), and Oman (2.62%). Saudi Arabia has a surplus of $104 million in pasta exports and imports, a surplus that has been particularly evident since 2010.

World and Türkiye export prices of pasta per unit (per ton, $)

According to FAO data from 1980-2024, when examining world and Turkish export prices of pasta per unit (per ton, $), although there are fluctuations, prices show an upward trend (Y_{WRLD} = 14.373x – 27818; R^2 = 0.5631). $Y_{TÜRK}$ = 7.4208x - 14373 R^2 = 0.4185) (Figure 2). Z

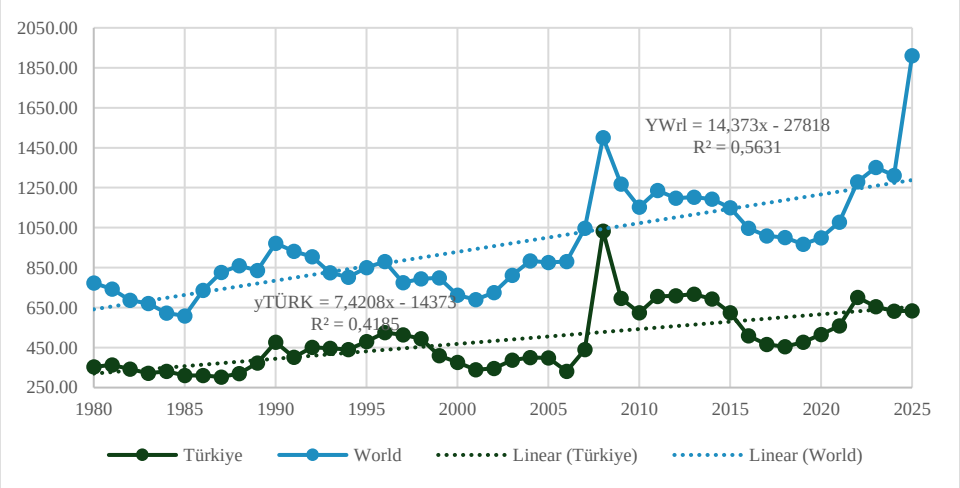


Figure 2. Turkish and global unit pasta export prices ($ per tonne) (FAOSTAT, 2026)

World export pasta prices per ton ranged from $608.85 to $860.36 between 1980 and 1989, hitting a low in 1985 and a peaking in 1988. During the same period, Türkiye's export pasta prices per ton ranged from $303.13 to $372.44, peaking in 1989 and hitting a low in 1987, remaining below $345 between 1982 and 1987. The world price was more than double the Turkish price. Türkiye's export unit price for pasta remained below the world price, with price volatility similar (World 9.59%, Türkiye 7.33%). The highest average export pasta price per ton between 1980 and 1989 was $1164.11 in the USA. Export pasta prices per ton ranged from $558.32 to $864.64 in Italy, $267.86 to $872.59 in China, $691.84 to $1279.01 in Germany, $750 to $1300.35 in Indonesia, $796.98 to $1143.56 in the Netherlands, $939.79 to $1375.60 in the Republic of Korea, $841.73 to $1512.44 in Saudi Arabia, and $539.27 to $678.85 in Thailand. Price volatility was high in Indonesia, Saudi Arabia, Germany, and China during this period (36.56%, 34.75%, 17.21%, and 16.29%, respectively). The coefficient of variation is also higher in China, Indonesia, Germany, and Saudi Arabia (44.11, 20.59, 19.14, and 18.71). Among the countries examined, the lowest export price per ton of pasta was observed in Türkiye, followed by China (Table 8).

Between 1990 and 1999, the world export price per ton of pasta rose to between $775.33 and $971.43. It peaked in 1990. The price fluctuated; it showed a decreasing trend. During this period, Türkiye's export price per ton of pasta rose to between $402 and $525.04. It peaked in 1996. The world price was approximately 85.37% higher than the Turkish prices. Türkiye's export unit price for pasta remained below the world price. During this period, the volatility of export prices in the world decreased to 7.97%, whereas it increased to 13.50% in Türkiye. The coefficients of variation were 7.78 and 8.95. Between 1990 and 1999, the highest average export price per ton of pasta was again recorded in South Korea at $1555.45. In Italy, the export price per ton ranged from $730.87 to $953.44, in the USA from $1062.93 to $1357.32, and in China from $495.87 to $917.10. Price volatility was higher in Thailand, Indonesia, and Germany during this period (28.32%, 23.58%, and 22.07%). The coefficient of variation was also higher in Indonesia, Saudi Arabia, and Germany (24.67, 24.06, and 21.46). Among the countries examined, the lowest export price per ton of pasta was recorded in Türkiye and China (Table 8).

Between 2000 and 2009, the world export price of pasta showed an upward trend, ranging from $689.66 to $1500.26. During this period, Türkiye's export price per ton of pasta showed a slight upward trend, ranging from $331.90 to $1033.15, peaking in 2008. Between 2000 and 2006, it remained below $400 per ton. The world price was more than double the Turkish price. Therefore, Türkiye's export unit price for pasta was below the world price.

During this period, export price volatility increased by 16.66% globally and 46.53% in Türkiye. The coefficients of variation increased to 27.94 and 46.87, respectively. The highest average export price per ton of pasta between 2000 and 2009 was again in Saudi Arabia at $2356.15. In Italy, the export price of pasta per ton ranged from $615.17 to $1575.64, in the Netherlands from $700.43 to $2670.49, in Indonesia from $804.45 to $1466.75, in Thailand from $869.80 to $1839.63, in the USA from $954.91 to $1467.18, and in China from $538.99 to $896.33. The coefficient of variation was high in Türkiye, the Netherlands, and Italy during this period (46.87, 39.62, and 34.26, respectively). Price volatility was also higher in Türkiye, Saudi Arabia, and Italy (46.53%, 32.19%, and 20.65%, respectively). The lowest export prices per ton of pasta among the countries examined were observed in Türkiye and China (Table 8).

Between 2010 and 2019, world export prices rose to a range of $967.28 to $1236.67, showing less volatility and peaking in 2011. During this period, Türkiye's export price per ton of pasta rose to a range of $455.35 to $717.52, reaching its highest value in 2013. Even during this period, the world price was approximately 89.73% higher than the Turkish price. Export price volatility decreased to 4.70% globally and 8.99% in Türkiye. The coefficients of variation also decreased to 8.90 and 18.46. The highest average export price per ton of pasta between 2010 and 2019 was $2415.99 in the Netherlands. In Italy, the export price of pasta per ton ranged from $1090.57 to $1271.68; in Thailand, from $1714.44 to $1937.16; in the USA, from $1328.93 to $1538.10; in China, from $942.76 to $1648.42; and in Germany, from $1596.60 to $1919.21. Price volatility was higher in Saudi Arabia and Indonesia during this period compared to other countries (12.10% and 10.94%). The coefficient of variation was also higher in Türkiye and Saudi Arabia (18.46 and 14.48). The coefficient of variation was also higher in Türkiye and Saudi Arabia (18.46 and 14.48). The lowest export price of pasta per ton among the countries examined was observed in Türkiye (Table 8).

Between 2020 and 2025, the global export price rose to a range of $998.78 to $1910.74. In 2025, it reached its highest point (1980-2025) at $1910.74. During this period, the export price per ton of pasta in Türkiye ranged from $515.42 to $700.79. Again, global prices were more than double the Turkish prices during this period. Between 2020 and 2025, the volatility of global export prices reached 17.47%, whereas in Türkiye, it reached 11.48%. The coefficients of variation were 24.24 and 10.91, respectively. The highest average export price per ton of pasta between 2020 and 2025 was recorded in the Netherlands ($4103.80. In Italy, the export price of pasta per ton ranged from $1163.08 to $1846.89; in Germany, from $1607.67 to $2735.95; in the USA, from $1484.55 to $2276.69; in Thailand, from $1921.74 to $2887.97; in China, from $1415.52 to $1801.93; in South Korea, from $2082.49 to $3806.42; and in Saudi Arabia, from $1846.14 to $2203.41. Price volatility was high in Indonesia, Germany, and the Republic of Korea during this period (27.72%, 26.10%, and 26.06%, respectively). The coefficient of variation was also higher in the Netherlands and the Republic of Korea (26.22 and 25.47, respectively). Among the countries examined, Türkiye recorded the lowest export price per ton of pasta (Table 8).

In general, the world export price between 1980 and 2025 ranged from $608.85 to $1910.74, exhibiting a fluctuating upward trend. The highest point in the examined period (1980-2025) was $1910.74 in 2025. 1985 and 1984 represent the lowest values for export prices per ton of pasta. During this period, Türkiye's export price per ton of pasta rose to between $303.13 and $1033.15, with 2008 being the highest. 1987, 1986, 1988, and 1983 represent the lowest values for export prices per ton of pasta (in these years, the export price per ton of pistachios was below $320). During this period, the average world price was more than double the Turkish price (Table 8).

The export price volatility in the world was 12.29% and in Türkiye 23.45% during the 1980-2025 period. The coefficients of variation were 26.65 and 31.62. In the average of 1980-2025, the highest export price per ton of pasta was $1745.49 in the Republic of Korea and $1722.13 in the Netherlands. In Italy, the export price of pasta per ton ranged from $558.32 to $1846.89; in China, from $267.86 to $1801.93; in the USA, from $954.91 to $2276.69; in Thailand, from $539.27 to $2887.97; and in Indonesia, from $750 to $1911.86. Price volatility was high in Saudi Arabia, Türkiye, and Indonesia during this period (24.13%, 23.45%, and 23.23%, respectively). The coefficient of variation was also higher in China, Thailand, the Netherlands, Italy, Türkiye, and Germany (49.03, 47.88, 45.87, 31.95, 31.62, and 30.08, respectively). The lowest export price of pasta per ton among the countries examined was observed in Türkiye (Table 8).

When examining the long-term development and trends of export prices per ton of pasta in the world and Türkiye, it is observed that export prices have shown a positive trend in the long term. In general, a significant upward trend began in the 2005s. In Türkiye, prices remained at relatively low levels in the period after 2013, and a partial recovery was observed after 2022. However, it has shown higher volatility than world prices (Figure 1).

Table 8. Unit export prices in major pasta-producing countries (FAOSTAT, 2026)

Years	China	Germany	Indonesia	Italy	Netherlands	Republic of Korea	Saudi Arabia	Thailand	Türkiye	USA	World
	Average price ($ per tonne)										
1980-1989	459.90	992.54	1007.07	704.20	1001.42	1140.77	1161.51	605.95	332.98	1164.61	736.79
1990-1999	729.91	1213.54	1037.12	837.05	1243.97	1555.45	1691.66	814.76	464.20	1150.53	853.46
2000-2009	694.09	1434.17	1081.85	905.16	1507.37	1765.53	2356.15	1227.58	475.02	1119.49	939.85
2010-2019	1345.21	1726.87	1342.83	1184.27	2415.99	2057.01	1628.42	1846.07	598.16	1425.68	1115.42
2020-2025	1583.31	1910.34	1327.28	1503.46	2921.77	2517.49	1953.91	2120.96	616.12	1755.63	1321.74
1980-2025	908.50	1415.94	1147.67	985.38	1722.13	1745.49	1727.66	1253.68	486.96	1285.59	964.91
	Coefficient of variance										
1980-1989	44.11	19.14	20.59	16.56	13.18	11.03	18.71	7.23	7.30	10.26	12.04
1990-1999	19.96	21.49	24.67	8.33	11.50	12.31	24.06	20.96	8.95	4.73	7.78
2000-2009	17.49	29.30	20.23	34.26	39.62	13.42	18.04	27.50	46.87	15.57	27.94
2010-2019	21.05	6.68	11.36	6.09	6.16	9.29	14.48	3.58	18.46	4.30	8.90
2020-2025	8.05	21.95	21.95	16.29	26.22	25.47	6.78	17.86	10.91	16.27	24.24
1980-2025	49.03	30.08	22.43	31.95	45.87	29.50	29.11	47.88	31.62	20.07	26.65
	Votality										
1980-1989	16.29%	17.21%	36.56%	13.12%	13.20%	12.47%	34.75%	8.80%	7.33%	8.14%	9.59%
1990-1999	16.81%	22.07%	23.58%	8.79%	14.76%	13.89%	13.17%	28.32%	13.50%	6.73%	7.97%
2000-2009	11.74%	18.51%	12.45%	20.65%	17.95%	10.06%	32.19%	13.33%	46.53%	9.31%	16.66%
2010-2019	9.19%	7.31%	10.94%	6.24%	9.17%	7.23%	12.20%	4.55%	8.99%	4.84%	4.70%
2020-2025	12.80%	26.10%	27.72%	8.32%	18.23%	26.06%	9.41%	16.32%	11.48%	10.70%	17.47%
1980-2025	14.41%	18.11%	23.23%	12.99%	15.25%	14.03%	24.13%	16.17%	23.45%	7.91%	12.29%

World Pasta Consumption and Demand

The global demand for pasta continues to increase, driven by factors such as ease of preparation, affordability, product variety, and culinary versatility with diverse sauces.

According to the IPO, Italy maintains the highest per capita pasta consumption globally, alongside its status as a leading producer; however, its consumption is expected to decline by 17 %, from 28 kg in 2005 to 23.3 kg in 2025. Conversely, several nations witnessed notable increases in per capita consumption over comparable periods: Tunisia recorded a 45% increase (from 11.7 to 17 kg), Greece registered a 40% growth (from 8.7 to 12.2 kg), Germany experienced a 60% surge (from 6.3 to 10.1 kg), and Egypt demonstrated a sixfold expansion (from 1.2 to 7.1 kg).

Moderate growth was observed in several other countries between 2005 and 2025: Peru (18% increase, from 8.4 to 9.9 kg), Chile (16% increase, from 8.3 to 9.6 kg), France (18% increase, from 7.4 to 8.7 kg), Hungary (15% increase, from 6.5 to 7.5 kg), Türkiye (30% increase, from 5.6 to 7.3 kg), Portugal (4% increase, from 6.7 to 7 kg), and Russia (10% increase, from 6 to 6.6 kg). Meanwhile, Iran recorded a 21% increase from 2010 to 2025 (rising from 7 kg to 8.5 kg), whereas Venezuela and the USA displayed contrasting trends, with Venezuela showing a marginal 3% increase (from 13 kg to 13.4 kg) and the USA a 2% decline (from 9.8 kg to 8.8 kg).

The Czech Republic, Canada, and Argentina are expected to have per capita pasta consumption exceeding 6 kg in 2025. Brazil, Estonia, Switzerland, Poland, Belgium, the Slovak Republic, Sweden, Bolivia, and Austria had a projected per capita pasta consumption of approximately 5 kg in 2025. Lithuania, Slovenia, Spain, Latvia, the Dominican Republic, and Australia had a projected per capita pasta consumption of approximately 4 kg in 2025. Except for Poland, Canada, Estonia, the Slovak Republic, Bolivia, Lithuania, and Latvia, these countries showed a trend of decreasing consumption, ranging from 5% to 15%.

Koç et al. (1996), in their study in Adana province, found the average monthly pasta consumption per family to be 2.41 kg in the summer and 2.74 kg per month in the winter. This indicates seasonal variations in pasta consumption. They calculated the annual per capita consumption of pasta to be 6.6 kg per year. However, they found that pasta consumption per capita increased with income group, and the annual pasta consumption per capita in high-income groups was 8.4 kg. They determined that being loved by children and being a practical meal affected families' pasta consumption relatively more. They found that the cheapness factor was relatively less effective among the factors affecting families' pasta consumption. They revealed that three important factors are effective in consumer brand preference. The first is the easy availability factor, the second is the product quality factor, and the third is the price factor.

Yurtsever (2007) found that 97.7% of families in Tekirdağ province consume pasta; they prefer chain stores and supermarkets as places to purchase pasta, every family cooks pasta at least once a month, and 62.2% consume pasta as the main course. Gül et al. (2017) examined consumption, preference, purchasing behaviour, and the factors influencing consumers of bakery products in 288 households in Isparta. They found that pasta was purchased monthly in the study area. Consumers stated that they preferred bakery products as delicious and filling snacks. They calculated the per capita monthly pasta consumption as 913.45 g. Muslu et al. (2021) found that 89.1% of university students in Gümüşhane province consumed pasta and consumed an average of 3–5 (600-1000 g) portions per month.

Gül et al. (2017) found that the brand addiction rate for pasta is high. They found that the rate of consumers who always preferred the same brand was 39.93%, and the rate of those who preferred two or three brands was 38.19%.

CONCLUSIONS

This study examined pasta production, consumption, foreign trade, and prices worldwide and in major pasta-producing countries. The findings demonstrate a significant and sustained increase in worldwide pasta production, consumption, and international trade volumes over recent decades, driven by technological advancements, changing dietary patterns, and expanding markets. Türkiye has notably advanced its position in the global pasta industry, rising from 14th to 2nd place in export volume by 2025, with a substantial share of production dedicated to exports. Despite global price increases, Türkiye maintains comparatively lower export prices, albeit with higher price volatility, highlighting both competitive advantages and challenges in market stability. The diversification of Türkiye’s export markets, especially the expansion into African and Asian countries, underscores the strategic importance of broadening trade relations to sustain growth and competitiveness.

Comparative analyses with other leading exporters such as Italy, China, South Korea, and Thailand reveal varied trade balances and competitiveness profiles, emphasising the role of raw material availability, technological innovation, and targeted market strategies in shaping sector performance. Given these insights, several recommendations emerge to strengthen Türkiye's pasta industry further, such as addressing challenges in durum wheat procurement through policies such as contract farming and improved agricultural support, which can secure stable input supplies and reduce production risks and costs. On the other hand, continued modernisation of production facilities and investment in research and development will improve product quality, operational efficiency, and innovation capacity, enabling Türkiye to maintain and expand its competitive edge. Strategic efforts to explore and consolidate emerging markets, especially in Africa and Asia, will mitigate risks associated with market concentration and enhance export resilience. Enhanced export incentives, market intelligence, and branding initiatives can amplify Türkiye's presence in global markets and improve price positioning. Developing mechanisms to anticipate and manage price fluctuations will help stabilise revenues and foster sustainable growth.

Overall, the growth trajectory of the global pasta sector and Türkiye's prominent role within it underscore the sector's strategic significance in the agricultural-based industrial landscape. By implementing these recommendations, Türkiye can consolidate its position as a major global pasta exporter while contributing to national economic development.

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PHENOLIC AND ORGANIC ACID PROFILES OF BLACK MULBERRY (MORUS NIGRA L.) GENOTYPES IDENTIFIED IN THE RURAL AREAS OF ESKISEHIR PROVINCE

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ABSTRACT
In this study, the phenolic compound and organic acid profiles of 20 different black mulberry (*Morus nigra* L.) genotypes identified in the rural areas of Eskisehir province were investigated. Eight phenolic compounds (gallic acid, caffeic acid, chlorogenic acid, p-coumaric acid, ferulic acid, protocatechuic acid, vanillic acid and sinapic acid) and eight organic acids (syringic acid, citric acid, malic acid, tartaric acid, oxalic acid, succinic acid, fumaric acid and ascorbic acid) were determined and quantified. Among phenolic compounds, the highest concentration was detected in gallic acid; the ES-BM-19 genotype was particularly prominent with 60.00 mg/100 g fresh weight. In the organic acid profile, citric acid was dominant across all genotypes, with ES-BM-19 reaching the highest value (1588.00 mg/100 g), while ES-BM-01 exhibited the highest malic acid content (528.00 mg/100 g). Correlation and Principal Component Analysis (PCA) revealed strong positive associations among phenolic acids while showing that malic acid was negatively correlated with the overall phenolic profile. Hierarchical cluster analysis grouped the genotypes into three main clusters based on their biochemical similarities. The results demonstrate that black mulberry genotypes native to the Eskisehir region harbor considerable phenolic and organic acid diversity, and the ES-BM-19 genotype stands out particularly in terms of high phenolic capacity.

Keywords: Morus nigra, phenolic compounds, organic acids, genotype, correlation analysis, principal component analysis

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THE EFFECT OF BIOSTIMULANT APPLICATIONS ON POMOLOGICAL VALUES IN BLACK CURRANT (RIBES NIGRUM L.)

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ABSTRACT
Blackcurrant (*Ribes nigrum* L.) is a temperate climate berry fruit species whose cultivation has gained momentum in our country in recent years; however, the extent to which biostimulant applications can alter the physical characteristics of the fruit and cluster is largely unknown. In this study, the effects of three different doses (500, 1000, and 1500 ppm) of four foliar-applied biostimulants—chitosan, seaweed extract, plant-derived amino acids, and inactive yeast—on the pomological characteristics of the 'Rosenthal' blackcurrant variety were determined. The experiment was conducted in a private farm in Aksu village, Kestel district, Bursa province, on 4-year-old plants at full yield, covering the 2026 vegetation period. The experiment was set up in a randomized block design with 3 replications and 5 plants in each replication; A total of 13 treatments (1 control + 4 biostimulants × 3 doses) and 65 plants were included. Biostimulants were sprayed foliar twice per season, during the first leafing and full leafing stages. Fruits were harvested at full maturity and evaluated for fruit weight (g), fruit width and length (mm), cluster weight (g), cluster length (mm), fruit color (L*, a*, b*), and yield per plant (g). Measurements were performed on 20 randomly selected fruits from each replicate using a 0.01 g precision balance, digital caliper, and colorimeter. Differences were observed among the biostimulants according to the results obtained.
Acknowledgements: This study is part of the first author's (Melike Urfalı) doctoral thesis.
Keywords: Ribes nigrum; biostimulant; foliar application; fruit size; cluster characteristics; fruit color; yield per plant

COMPETITIVE SECURITIZATION: HOW ARE GLOBAL CONFLICTS UNDERMINING THE POLITICAL PRIORITY OF THE CLIMATE CRISIS?

REKABETÇI GÜVENLIKLEŞTIRME: KÜRESEL ÇATIŞMALAR İKLIM KRIZININ SIYASAL ÖNCELIĞINI NASIL ZAYIFLATIYOR?

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ABSTRACT
In 2025, global military expenditure rose by 2.9 per cent in real terms to 2.887 trillion dollars, marking the eleventh consecutive year of growth. Over the same period, the volume of global climate crisis reporting fell by 14 per cent compared with 2024 and by 38 per cent compared with the 2021 peak. This paper examines the mechanisms through which the political priority of the climate crisis changes when security crises intensify. Russia's invasion of Ukraine, the Gaza-centred regional conflict that began in October 2023, the Twelve-Day War among Iran, Israel and the United States in June 2025, and the inauguration of the Trump administration in January 2025 are treated as the main breaking points, while the conflict that reignited in February 2026 is assessed as the current period. The study explains this relationship through the climate security literature, the agenda-setting and crowding-out approaches, and classical and neoclassical realism. It integrates these literatures into a single testable model through three channels, financial, discursive and institutional, and names this approach competitive securitization. Testable hypotheses are developed for each channel, and a mixed-methods design is proposed that combines event studies, country-year panel analyses, Bayesian structural time series and qualitative content analysis. The contribution is not the discovery of a new mechanism but the integration, within a single testable and methodologically transparent framework, of mechanisms that have been examined separately across different literatures.
Keywords: competitive securitization, climate security, agenda-setting, crowding-out, realism, climate finance, arms race

ÖZET
Küresel askeri harcamalar 2025 yılında reel olarak yüzde 2,9 artarak 2,887 trilyon dolara ulaşmış ve art arda on birinci büyüme yılını kaydetmiştir. Aynı dönemde küresel iklim krizi haberciliğinin hacmi 2024 yılına göre yüzde 14, 2021 yılındaki zirveye göre yüzde 38 gerilemiştir. Bu bildiri, güvenlik krizlerinin güçlendiği dönemlerde iklim krizinin siyasal önceliğinin hangi mekanizmalar üzerinden değiştiğini incelemektedir. Rusya'nın Ukrayna'yı işgali, Ekim 2023'te başlayan Gazze merkezli bölgesel çatışma, Haziran 2025'te İran, İsrail ve ABD arasında yaşanan On İki Gün Savaşı ve Ocak 2025'te Trump yönetiminin göreve başlaması temel kırılma noktaları olarak ele alınmakta, Şubat 2026'da yeniden alevlenen çatışma ise güncel dönem olarak değerlendirilmektedir. Çalışma bu ilişkiyi iklim güvenliği yazını, gündem rekabeti ve crowding-out yaklaşımı ile klasik ve neoklasik realizm üzerinden açıklamaktadır. Bu literatürler mali, söylemsel ve kurumsal olmak üzere üç kanal üzerinden tek bir sınanabilir modelde birleştirilmekte ve bu yaklaşım rekabetçi güvenlikleştirme olarak adlandırılmaktadır. Her kanal için sınanabilir hipotezler geliştirilmekte, olay çalışmaları, ülke-yıl panel analizleri, Bayesçi yapısal zaman serisi ve nitel içerik analizini bir araya getiren karma yöntemli bir tasarım önerilmektedir. Çalışmanın katkısı yeni bir mekanizma keşfetmekten çok, farklı literatürlerde ayrı incelenen mekanizmaları tek bir sınanabilir ve yöntembilimsel olarak açık çerçevede birleştirmektir.
Anahtar kelimeler: rekabetçi güvenlikleştirme, iklim güvenliği, gündem rekabeti, crowding-out, realizm, iklim finansmanı, silahlanma yarışı

INTRODUCTION

Global military spending has risen significantly in recent years. In 2025, this spending increased by 2.9 percent in real terms, reaching $2.887 trillion, and marked its eleventh consecutive year of growth (Liang et al., 2026). During the same period, the volume of global climate crisis coverage declined by 14 percent compared to 2024 and by 38 percent compared to its 2021 peak; this decline was particularly pronounced in Africa, the Middle East, Europe, and North America (MeCCO, 2026). The fact that the rise in military spending coincided with a decline in the public and political visibility of the climate crisis raises the question of what relationship exists between these two trends. While the IPCC's (2023) Sixth Assessment Report emphasizes that the window of opportunity for action toward a livable and sustainable future is rapidly narrowing, it highlights the need to explain the discrepancy between the growing scientific urgency of the climate crisis and the potential decline in its political priority.

Rather than explaining this relationship solely through concurrent developments, this study investigates the mechanisms through which competing security crises might influence the political priority of climate issues. The central question of the study is: Through which channels and under what conditions can competing securitized crises undermine the political priority of climate issues? This question is addressed through three channels: financial, discursive, and institutional. The financial channel focuses on budgetary competition between defense spending and climate finance; the discursive channel examines the impact of conflict and security news on the visibility and framing of the climate agenda; and the institutional channel focuses on changes in the level of political attention and representation at the Conferences of the Parties.

The study examines current geopolitical developments through the lens of four pivotal events. These are Russia's invasion of Ukraine; the Gaza-centered conflict that began in October 2023 and expanded to a regional scale; the Twelve-Day War between Iran, Israel, and the U.S. in June 2025; and the inauguration of the Trump administration in January 2025 (Council on Foreign Relations, 2026). The Iran-Israel-U.S. conflict, which reignited in February 2026, is evaluated separately as the study's current period. Not all of these events are treated as having the same causal status. While the first three are direct geopolitical and security crises, the Trump administration's inauguration is assessed as a political policy break representing a shift in security and energy policy. This distinction prevents the establishment of an overly strong assumption that the events are all of the same type of external shock.

The theoretical starting point of this study is that the literature on climate security, agenda competition, and realism explains different dimensions of the same phenomenon. While the climate security literature discusses the effects of security policies on climate policies and environmental cooperation, the literature on agenda competition and crowding-out explains how limited political and media attention is distributed among various issues. Classical and neoclassical realism, meanwhile, offer a complementary framework that explains why concerns about security and relative power in the international system can, at certain times, take precedence over climate cooperation. This study treats these approaches not as alternatives to one another, but as complementary perspectives that explain different levels of the same causal process, and in this vein, proposes the concept of "competitive securitization." The concept is based on the assumption that the competition over prioritization arising among securitized crises can manifest not only at the discursive level but also through financial and institutional channels.

The study focuses on four research questions. The first examines whether there is an inverse relationship between increases in defense spending and the fulfillment rate of climate finance commitments, corresponding to the financial channel. The second examines whether the share of climate crisis news in the overall news agenda decreases when the volume of conflict news increases, and whether there is a shift in the framing of climate news, corresponding to the discursive channel. The third investigates whether the level of state representation at Conference of the Parties (COP) meetings following major geopolitical shocks has declined, corresponding to the institutional channel. Fourth, it questions whether the observed loss of climate priority is better explained by factors independent of conflict or by a competing securitization mechanism. The study does not provide definitive empirical answers to these questions at this stage but proposes a mixed-methods research design that links each mechanism to measurable indicators. Thus, the focus shifts from the question of why the climate crisis remains unresolved to the question of why and through which mechanisms the political priority of climate issues changes during periods of intensified security crises.

THEORETICAL FRAMEWORK AND CONCEPTUAL MODEL

Conceptual Framework and Gaps in the Literature

To determine whether one crisis influences another, it is necessary to evaluate multiple theoretical approaches together. The primary reason for this is that each approach focuses on a different dimension of the problem and, on its own, may be insufficient to explain the relationship in its entirety. While the original formulation of agenda-setting theory posits that the media shapes which issues are perceived as important, it does not systematically address competition among issues (McCombs et al., 2014; McCombs & Shaw, 1972). Hilgartner and Bosk (1988), on the other hand, defined public attention as a scarce resource when modeling the rise and fall of social issues, demonstrating that issues compete to enter the agenda and remain there due to the limited carrying capacity of public discourse spaces. Zhu (1992) empirically tested this logic by modeling it as a zero-sum game, while Ungar (1992) applied the approach directly to the global warming debate to explain the issue's rise and relative decline as a social problem. Downs' (1972) concept of the "problem-attention cycle" further complements this picture, emphasizing that social problems rapidly enter the public eye and gain high visibility for a short time, but can drift away from the center of attention over time, even if the problem remains largely unresolved.
The Copenhagen School's theory of securitization argues that an issue can be removed from the realm of ordinary political debate as a result of its being presented and accepted as an existential threat (Buzan et al., 1998). While this approach provides a strong framework for explaining how an issue is transformed into a security issue, its primary focus is on the construction of a single issue as a threat. Consequently, the question of how an issue that has already been securitized might lose priority in the face of another securitized issue is not a matter directly addressed by the theory. While Karyotis et al., (2025) draw attention to the threat perceptions generated by crises such as those in Ukraine and Gaza in conjunction with the climate crisis through the concept of "perpetual crisis," they do not model how these threats engage in a systematic competition for priority as a distinct mechanism. Beck's (1992) risk society approach, however, helps explain the basis of this prioritization problem at the level of social perception, demonstrating that traditional threats—which are more concrete and immediate—and modern risks—such as climate change, which are more diffuse and have consequences that unfold over time—can give rise to differences in prioritization among crises.
The question of whether the climate crisis is a security issue has been the subject of an extensive body of literature (Corry, 2012; McDonald, 2013; Oels, 2012; Rothe, 2015; Trombetta, 2008). Within this literature, Egeland's (2022) approach is significant in terms of the focus of this study. Egeland focuses not so much on how the climate crisis affects security policies, but rather on how security policies might influence climate policies. He highlights how security spending can compete with public resources that could be used for the green transition, how states' security preferences can influence the priorities of other states, and how security competition can undermine the conditions for environmental cooperation. A more recent systematic study also highlights the significant share of military activities in global greenhouse gas emissions, demonstrating that security policies are not merely an indirect issue from the perspective of climate policy (Ragoobur et al., 2026).
There has also been a long-standing body of literature on the discursive channel. The theoretical foundation of this literature extends from Hilgartner and Bosk's (1988) carrying capacity approach to Zhu's (1992) zero-sum agenda model; one of its applications in the field of media attention can be seen in Djerf-Pierre's (2012a) study. By examining long-term changes in Swedish television news, Djerf-Pierre demonstrates that environmental news can be pushed into the background during periods when high-priority issues such as war and the economy take center stage. Djerf-Pierre also points out that, in addition to topic competition, "topic fatigue" can also explain shifts in news interest. This distinction is important for the study's model because the decline in climate news may arise not only from the rise of another topic but also from a decrease in interest in the climate issue due to its own internal dynamics. For this reason, topic fatigue is also considered as an alternative explanation to competitive securitization. Rauchfleisch et al., (2021) also examined the COVID-19 period and demonstrated how the crisis agenda could influence media and social media interest in climate change.
When these studies are evaluated together, it becomes evident that security studies and communication studies examine a closely related phenomenon from different perspectives. The common thread is that they demonstrate how the climate issue can be pushed into the background in various ways when security and crisis agendas gain prominence.

However, existing studies do not address the financial, discursive, and institutional impacts collectively within the same causal model. The study's claim of a gap in the literature emerges precisely at this point, and the climate security approach is examined in conjunction with the literature on agenda competition and crowding-out, as well as the realist approach that explains concerns regarding security, survival, and relative power.

The concept of "competitive securitization" proposed here is not presented as a new general theory that replaces existing concepts in these three bodies of literature. The concept is used to name the competition over prioritization that arises among securitized crises and to enable the examination of this competition through different channels. The concept of issue competition focuses primarily on competition between political and media agendas (Green-Pedersen & Mortensen, 2010), while the crowding-out approach explains the exclusion of resources or attention in the economic and communication literatures. Securitization theory, on the other hand, explains the construction of an issue as a threat but does not directly model the competition for prioritization among securitized issues. Although Hilgartner and Bosk's (1988) public spheres approach explains the competition among issues for limited attention, it does not address budget allocation and institutional decision-making processes within the same framework. Therefore, the study's claim to originality is not merely to introduce a new concept. The main contribution lies in integrating the competition for financial resources, media attention, and the political agenda—which are typically examined separately across different disciplines—with shifts in institutional attention and representation within a single research problem.

Realism, Power Politics, and the Marginalization of Climate

Security theory and the crowding-out literature offer important explanations for why the climate crisis may take a back seat on the agenda. However, realism provides a complementary framework for understanding why states are able to systematically prioritize the security domain. Waltz's (1979) structural realism argues that, due to the anarchic nature of the international system, states act primarily out of concerns for survival and security. Mearsheimer's (2001) offensive realism takes this approach further by arguing that great powers aim to maximize their relative power as much as possible, while Jervis's (1978) concept of the security dilemma demonstrates that measures taken by a state to enhance its security may be perceived as a threat by other states and lead to a spiral of mutual arms buildup. When these approaches are considered together, it becomes evident that the increase in security spending may stem not only from the short-term preferences of individual states but also from security competition within the international system.

Although there is no direct theory of realism regarding climate policy, studies addressing the topic explain certain aspects of this connection. Purdon (2014), working within a neoclassical realist framework, argues that climate finance commitments are not entirely independent of states' concerns about relative gains and are linked to existing official development assistance budgets, thereby indicating that climate finance must be evaluated within the context of budgetary constraints. Consequently, Purdon's approach provides a theoretical foundation for the study's financial channel. However, this study interprets this finding not as a direct causal relationship between defense spending and climate finance, but rather as an indication that security and climate expenditures must be evaluated within the context of broader resource competition. Rose (1998), on the other hand, argues within the framework of neoclassical realism that systemic pressures do not directly determine state behavior; rather, these pressures are shaped through states' internal political and bureaucratic structures. This approach explains why the same security constraint can produce different outcomes in different countries and provides a basis for the regime type and per capita income moderators in the model. Per capita income is used here as an indicator that roughly represents the state's fiscal and economic capacity, while the theoretical basis for the media system moderator stems from the comparative media systems literature (Hallin & Mancini, 2004).

The distinction between realist and securitization explanations is methodologically significant. While securitization theory focuses on how an issue is constructed as a threat, realism seeks to explain the material interests, power distribution, and systemic pressures underlying security priorities. For this reason, the two approaches are not considered alternatives but rather complementary approaches that address different levels of explanation. Within this framework, the intensity of rival securitization—used as an independent variable in the model—is not merely a discursive measure.

The set of indicators—comprising the number of conflicts, conflict intensity, and the rate of increase in military spending—aims to capture both the level of conflict and the strengthening of the security agenda in terms of material resources, thereby enabling a connection to be established between the material security pressures emphasized by the realist approach and the threat prioritization emphasized by the securitization approach.

Conceptual Model and Hypotheses

The model posits a fundamental causal direction ranging from geopolitical shocks to the political prioritization of climate. The four breaking points at the beginning of the chain serve as starting points for an event-based comparison to examine changes in the intensity of rival securitization. This is measured through the independent variables of rival securitization intensity, conflict intensity, number of conflicts, and increases in military spending. Conflict data are drawn from the UCDP Geographically Referenced Event Dataset (Sundberg & Melander, 2013) and ACLED (Raleigh et al., 2010), while military expenditure data are compiled from the SIPRI database (Liang et al., 2026). The dependent variable—the political priority of climate—is represented by a composite index consisting of the climate finance implementation rate, the degree of legal bindingness of Conference of the Parties agreements, and the frequency of climate references in official discourse. After the three components are standardized, they are combined with equal weights; the impact of the weighting choice is tested through sensitivity analysis. The degree of legal binding is coded in accordance with Abbott and Snidal's (2000) legalization framework, and Vihma (2013) demonstrates the applicability of this approach to the UN climate regime.

The relationship between the two variables is not direct but is explained through three complementary mechanisms. The financial channel (M1) reflects competition over resource allocation between defense and climate budgets; the discursive channel (M2) reflects competition over visibility and framing between climate issues and other security priorities; and the institutional channel (M3) reflects changes in the continuity of institutional attention to climate and climate commitments. Each channel is analyzed using measurable indicators. The financial channel is measured by the ratio of climate finance to defense spending (Egeland, 2022; Fan et al., 2018; Purdon, 2014); the discursive channel by the share of climate news in the overall news agenda and shifts in framing (Djerf-Pierre, 2012a; Rauchfleisch et al., 2021); and the institutional channel is measured by the political level of Conference of the Parties delegations and the continuity of commitments (Blinova et al., 2024). It is assumed that the impact of these channels is not the same under all conditions; it is anticipated that the impact may vary depending on country characteristics such as regime type, media environment, and gross domestic product per capita. Regime type is measured using V-Dem's Electoral Democracy Index (Coppedge et al., 2025), while the media environment is measured using V-Dem's alternative data sources index, as Hallin and Mancini's (2004) typology cannot be directly applied to the global panel. Since there is component overlap between the two moderators, the models first use the moderators separately and then together, and multiple correlation diagnoses are reported.

Table 1. Variables, Channels, and Metrics of the Competitive Securitization Model

Model Component	Definition	Indicator
Independent variable	Rival security buildup intensity	Conflict intensity and number (UCDP GED, Sundberg ve Melander, 2013; ACLED, (Raleigh et al., 2010)) and rate of increase in military spending (SIPRI, (Liang et al., 2026))
Fiscal Channel (M1)	Competition Between Defense and Climate Budgets	The Ratio of Climate Finance to Defense Spending ((Egeland, 2022; Fan et al., 2018; Purdon, 2014))
Discursive channel (M2)	Agenda-setting and framing competition	Changes in the share of climate news on the agenda and in news framing ((Djerf-Pierre, 2012a; Rauchfleisch et al., 2021))

Institutional channel (M3)	Shift in institutional attention and commitment	COP delegation/representation level and the continuity of commitments ((Blinova et al., 2024; Egeland, 2022))
Dependent variable	Political priority of climate (composite index)	Climate finance implementation rate; degree of COP bindingness (Abbott & Snidal, 2000; Vihma, 2013); and frequency of climate references in official discourse
Moderators	Country characteristics that influence the strength of the relationship	Regime type and media system ((Coppedge et al., 2025; Hallin & Mancini, 2004)) and GDP per capita ((World Bank, 2025))

The first hypothesis proposed for the fiscal channel posits that there is a negative relationship between the annual real increase in defense spending and the implementation rate of climate finance commitments. The second hypothesis, however, argues that this relationship will vary depending on a country's fiscal capacity. In countries with high fiscal capacity, the crowding-out effect is expected to be more limited because defense and climate initiatives can be financed simultaneously; in countries with low fiscal capacity, however, the effect is expected to be more pronounced due to more binding budget constraints. This expectation is consistent with findings showing that the trade-off between defense spending and other public expenditures is not fixed (Carter et al., 2021).

H1a. There is a negative relationship between the annual real increase in a country's defense spending and the fulfillment rate of its climate finance commitments.

H1b. This negative relationship is stronger in countries with lower per capita income.

The discursive channel is tested based on two hypotheses. The first predicts that during periods when the volume of conflict news increases, the share of climate news in the agenda will decrease (Djerf-Pierre, 2012a). The second hypothesis argues that during periods of heightened conflict intensity, the framing of climate news will shift from ecological issues toward energy security and geopolitical risks, thereby suggesting that the discursive channel affects not only the volume of news but also the conceptual framework within which the climate issue is presented.

H2a. As the volume of conflict-related news increases, the share of climate crisis coverage in the overall news agenda decreases.

H2b. During periods of heightened conflict, the focus of climate news shifts from ecological issues to energy security and geopolitical risks.

The first hypothesis regarding the institutional channel predicts that the level of representation of the parties decreases at summits following major geopolitical shocks. This decrease is indicated by participation by lower-level delegations rather than heads of state or government, and the level of representation is coded hierarchically according to the participant's protocol rank (Blinova et al., 2024). The second hypothesis posits that the frequency of climate references in official discourse is negatively correlated with conflict intensity. The frequency of climate references in official discourse is modeled not as an independent indicator of the institutional channel but as a separate dependent variable distinct from the composite political priority index. This approach reduces the risk of circularity that might arise from defining both the institutional channel and the dependent variable through the same indicator.

H3a. At Conferences of the Parties following major geopolitical shocks, the level of state representation declines.

H3b. An increase in the intensity of conflict reduces the frequency of references to climate in official discourse.

Robustness tests are conducted to assess the model's sensitivity to alternative explanations. These tests examine whether the relationships predicted in H1–H3 persist when controlling for media economy and news consumption indicators (Newman et al., 2025), general macroeconomic contraction, and topic fatigue. Controlling for topic fatigue helps assess whether a potential decline in climate news stems from competitive securitization or from the topic losing its appeal on the agenda over time ((Djerf-Pierre, 2012a).

H0. The relationships predicted in H1–H3 lose their statistical significance when media economy indicators, general macroeconomic contraction, and topic fatigue are controlled for.

METHOD

To minimize potential issues related to causality, the study employs four political and geopolitical turning points. These are Russia's invasion of Ukraine; the Gaza-centered conflict that began in October 2023 and expanded to a regional scale; the Twelve-Day War between Iran, Israel, and the U.S. in June 2025; and the inauguration of the Trump administration in January 2025. The Iran-Israel-U.S. conflict, which reignited in February 2026, is also addressed separately to evaluate the study's current period. While these events create distinct ruptures in the fields of security and foreign policy—distinct from the internal dynamics of climate policy—they are not considered entirely exogenous; the strength of causal inferences is supported by the modeling of pre-event trends, control variables, and counterfactual comparisons.

The study is based on a mixed-methods design. Quantitative analyses employ country-year panel regressions and Bayesian structural time-series models to assess the effects of events over time. The panel regressions test H1a and H1b within the framework of the financial channel, allowing for the control of unobservable and time-invariant country characteristics through country and year fixed effects. The Bayesian structural time series approach is used to test H2a within the discursive channel, comparing the news series observed after the break with the counterfactual series that would have been expected had the break not occurred (Brodersen et al., 2015). This allows for an assessment of the extent to which the observed change diverges from the trend that continued prior to the break and whether it can be explained solely by topic fatigue. In qualitative analyses, under H2b, changes in the framing of climate news are examined through content and discourse analysis (Fairclough, 1995); under H3a, delegations to the Conference of the Parties are analyzed using ordinal coding based on their protocol positions; and under H3b, the frequency and context of climate references in official statements are examined. The research is based on a mixed-methods design. In the quantitative analyses, country-year panel regressions and Bayesian structural time-series models are used to assess the impact of events over time. The panel regressions test H1a and H1b within the financial channel, with country and year fixed.

Table 2. Proposed Methods and Data Sources Based on the Hypotheses

Hypothesis /Analysis	Method	Data Source
H1a, H1b	Country-year panel regression and fixed-effects model	SIPRI, OECD DAC, Green Climate Fund, World Bank
H2a	Bayesian Structural Time Series and Counterfactual Impact Analysis	GDELT, News Archives
H2b	Content analysis and discourse analysis	GDELT, Reuters, AP, AFP, The New York Times, The Wall Street Journal, and other news archives
H3a	Sequential coding and time-series analysis	UNFCCC Party Participant Lists and COP delegation records
H3b	Content Analysis and Time Series Analysis	Official Statements by the UN, UNFCCC, NATO, the EU, and National Governments
Robustness tests	Panel and time-series models with control variables	Media economy, macroeconomic, and topic fatigue indicators

Panel regressions and country-year analyses are conducted from 2010 through the most recent completed observation year, to the extent permitted by the data sources. Since data for 2026 are not yet complete, only indicators for which data are available are used for that year, or the 2026 observations are evaluated in a separate analysis of the current period. In event studies, time windows are used to compare periods before and after breaks; for events with sufficient observation periods, 12- to 18-month windows are preferred. In particular, the Iran-Israel-U.S. conflict, which reignited in February 2026, is addressed within the scope of a current-period and early-impact analysis rather than a long-term event study, given that the data period is not yet complete; this prevents drawing long-term conclusions based on incomplete observations.

In qualitative data analysis, inter-coder agreement is assessed using Cohen's Kappa coefficient (Cohen, 1960). According to Landis and Koch's (1977) classification, values between 0.61 and 0.80 correspond to a substantial level of agreement; however, in this study, a more conservative approach is taken, and $\kappa \geq 0.70$ is used as the acceptable threshold. Pilot coding is conducted prior to the main analysis, and categories deemed necessary are redefined. GDELT is used to track changes in news volume in the discursive channel (Leetaru & Schrodt, 2013), while the determination of the news frame is not left solely to automatic volume indicators but is also examined through predefined coding categories. In this way, changes in the number of news stories are distinguished from the interpretive framework within which the news is presented.

DISCUSSION AND CONCLUSION

Which of the three channels provides a stronger empirical explanation will shape the theoretical and policy implications of this study. If the fiscal channel is found to be stronger, it may be concluded that climate finance should be shielded from the budgetary pressures created by defense spending, particularly in countries with limited fiscal capacity. Such a finding would support the resource competition mechanisms discussed by Egeland (2022) and Purdon (2014); meanwhile, the fact that the fiscal channel is weaker in high-income countries and more pronounced in low- and middle-income countries would be interpreted not as a failure but as support for the conditional relationship proposed in H1b. Stronger results for the discursive channel would indicate that security crises can influence not only the distribution of public resources but also which issues appear on the agenda. The prominence of the institutional channel, meanwhile, will indicate that geopolitical crises can influence the operating mechanisms and levels of political representation within international climate institutions; however, this finding should not be directly translated into a policy conclusion that the COP calendar must be made entirely independent of such crises.

The model is not presented as a universal law. The main reason for this is that the relationship between security crises and the climate agenda may not always manifest as competition under all circumstances. Djerf-Pierre's (2012b) work shows that, at certain times, environmental issues can rise in prominence together rather than diminishing each other's visibility. This type of "crowding-in" scenario is not a direct contradiction to the model, as the study examines potential competition between the climate agenda and the security agenda, rather than competition among environmental issues themselves. Similarly, Oels's (2012) concept of "climatization" demonstrates that security institutions can incorporate the climate agenda into their own discourses rather than simply excluding it; thus, the strengthening of the security agenda does not necessarily imply a weakening of the climate agenda. Rather than invalidating the model, this situation makes the question of under what conditions competitive securitization emerges all the more important.

One of the study's most significant methodological limitations is the possibility of reverse causality. A decline in the political priority given to the climate crisis could weaken international cooperation in the field of climate policy, and as a result, the likelihood of new conflict dynamics emerging may increase. Studies examining the relationship between climate variables and conflict have reached varying conclusions. While Hsiang et al., (2011) argue that there is a strong relationship between climate variables and the risk of conflict, Buhaug (2010) demonstrated that this relationship is more limited when different model specifications and alternative indicators are used, and Mach et al. (2019) evaluated the literature within a more comprehensive framework. Ide (2025), on the other hand, highlights the bidirectional nature of the relationship by arguing that climate action—or inaction—can also generate conflict. Therefore, it is not assumed that the relationship between climate and conflict is unidirectional or universal. This uncertainty is partially mitigated in the study through the use of an event study and a counterfactual time-series design, though it cannot be entirely eliminated. For this reason, the study proposes a design aimed at strengthening causal explanations rather than one that definitively proves causality.

The key contribution of realist theory to this study is that, rather than explaining security competition solely through the characteristics of individual crises, it offers a broader structural framework that takes into account states' relative power and security concerns.

Although the Russia-Ukraine war, the regional conflict centered on Gaza, and the conflict between Iran, Israel, and the U.S. have taken place in different regions and involved different actors, they provide comparable examples in terms of the growing importance of security concerns in political decision-making processes. However, this similarity does not mean that realism alone is sufficient. While realist theory explains why states engage in security competition, it does not, on its own, explain through which financial, discursive, and institutional channels this competition affects climate policy. The study's primary contribution lies in this area, as it aims to make realism, the securitization approach, and crowding-out debates testable within the same empirical model. The inclusion of conditions such as fiscal capacity, regime type, and media system in the model makes it possible to examine why the same geopolitical fracture can produce different outcomes in different countries.

If empirical findings support the competitive securitization mechanism, two key policy areas may come to the fore. First, financial mechanisms could be developed to ensure that climate finance is protected from periodic increases in defense spending, particularly in countries with limited fiscal capacity. Second, institutional arrangements could be established to ensure the continuity of international climate finance during times of crisis. If the discursive channel proves more effective, policy recommendations should also include communication tools that maintain the visibility of the climate agenda during security crises; if the institutional channel takes precedence, ensuring high-level political participation in international negotiations during times of crisis will become crucial.

Three areas stand out for future research. First, the proposed design must be applied using real data for at least one channel, and the hypotheses must be directly tested. Second, the conditions under which alternative mechanisms—such as crowding-in and climate adjustment—arise can be examined in greater detail. Third, to address the issue of reverse causality more robustly, longitudinal studies tracking pre- and post-crisis periods over longer time spans could be conducted. This study focuses not so much on the question of why the climate crisis remains unresolved, but rather on the question of under what conditions the climate issue loses its political priority. This choice is deliberate. The aim of the study is not to explain the content of climate policy on its own, but to examine the changes that security and geopolitical crises bring about in terms of political attention, financial resources, and institutional capacity, and to propose a testable model that reveals why and through which mechanisms the climate agenda can be pushed to the background during times of crisis.

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MICROPLASTIC POLLUTION IN AQUACULTURE: SOURCES, BIOLOGICAL IMPACTS, AND MANAGEMENT STRATEGIES

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ABSTRACT
Aquaculture is a strategic production sector, meeting the growing demand for animal protein from a rapidly expanding global population, and it is increasingly vulnerable to the impacts of environmental pollutants. In recent years, microplastic pollution, which has become widespread globally, has emerged as a serious environmental problem, threatening not only natural aquatic ecosystems but also aquaculture production systems. Microplastics can be transferred from the environment into aquaculture systems and also form in production areas due to the wear and tear of nets, cages, ropes, feed bags, and other polymer-based equipment.
This study aims to assess the main sources of microplastic pollution in aquaculture, their biological impacts on farmed organisms, and current management strategies for reducing pollution levels. Current research shows that microplastics can accumulate in tissues such as the digestive system, gills, and liver of fish and other farmed aquatic organisms, leading to various biological consequences, including oxidative stress, inflammation, histopathological changes, impaired immune function, slowed growth, and reduced reproductive success. Furthermore, microplastics can carry heavy metals, pesticides, and persistent organic pollutants, exacerbating toxic effects and increasing potential risks to food safety.
The use of more sustainable and environmentally friendly aquaculture materials, improved waste management, the implementation of regular environmental monitoring programs, and the widespread use of standardized analytical methods are essential for controlling microplastic contamination. This contamination poses a multifaceted threat to environmental sustainability, production efficiency, and food security in aquaculture. The aim of this study is to contribute to sustainable aquaculture practices and guide future research by comprehensively assessing existing knowledge on microplastic contamination in aquaculture.
Keywords: Aquaculture, microplastics, aquaculture, biological impacts, sustainability

TARIMSAL TOPRAKLARDAN KAYNAKLANAN N_2O EMİSYONLARININ AZALTILMASI İÇİN ÜRE VE NBPT İNHİBİTÖRLÜ ÜRE KULLANIMININ OPTİMİZASYONU

OPTIMIZATION OF UREA AND NBPT INHIBITOR-CONTAINING UREA USE FOR REDUCING N_2O EMISSIONS FROM AGRICULTURAL SOILS

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ÖZET

Günümüz tarımında bitkisel üretkenliğin artırılması açısından büyük önem taşıyan azotlu gübrelerin yoğun kullanımı, başta güçlü bir sera gazı olan nitröz oksit (N_2O) emisyonları olmak üzere önemli çevresel sorunlara yol açmaktadır. Bu çalışmada, çevre dostu bir teknoloji ürünü olan üreaz inhibitörü NBPT ile işlem görmüş ürenin topraktaki azot dinamikleri ve N_2O emisyonları üzerindeki etkileri araştırılmıştır. Türkiye tarım topraklarını temsil eden toprak örneklerine, kontrollü laboratuvar inkübasyon koşullarında farklı oranlarda geleneksel üre ve NBPT inhibitörlü üre uygulanmıştır. Azot dönüşüm süreçlerinin değerlendirilmesi amacıyla nitrat konsantrasyonları analiz edilmiş, N_2O emisyonları ise gaz kromatografisi kullanılarak belirlenmiştir. Araştırmada, toprak verimliliğini korurken N_2O emisyonlarını en aza indirecek optimum gübre karışım oranlarının belirlenmesi amaçlanmıştır. Bu kapsamda %100 üre, %25 üre–%75 inhibitörlü üre, %50 üre–%50 inhibitörlü üre, %75 üre–%25 inhibitörlü üre ve %100 inhibitörlü üre uygulamaları değerlendirilmiştir. Mevcut literatürle uyumlu olan ön bulgular, inhibitör içeren gübrelerin toprak türüne, nem düzeyine ve uygulama yöntemine bağlı olarak N_2O emisyonlarını %87'ye varan oranlarda azaltabileceğini göstermektedir. Deneysel sonuçlar, %50 geleneksel üre–%50 inhibitörlü üre karışımının optimum gübreleme stratejisi olduğunu ortaya koymuştur. Bu çalışma, sürdürülebilir tarım uygulamalarında hassas gübrelemenin önemini vurgulamaktadır. Gübre bileşiminin ve uygulama yöntemlerinin optimize edilmesiyle çevresel sürdürülebilirliği ve toplum sağlığını destekleyen azot yönetimi stratejilerinin geliştirilmesine katkı sağlanmaktadır. Elde edilen bulguların iklim değişikliğinin azaltılmasına yönelik çalışmalara katkı sunması, sürdürülebilir arazi kullanımını teşvik etmesi ve tarım politikalarının geliştirilmesine bilimsel temel oluşturması beklenmektedir.

Anahtar kelimeler: Üreaz inhibitörü; nitröz oksit emisyonları, azotlu gübreler; toprak azot dinamikleri; sürdürülebilir tarım.

ABSTRACT

Contemporary agriculture's heavy reliance on nitrogenous fertilizers, while essential for enhancing crop productivity, poses significant environmental challenges, particularly regarding the emission of nitrous oxide (N_2O), a potent greenhouse gas. This study investigates the effects of urease inhibitor-treated urea (NBPT), a green technology product, on soil nitrogen dynamics and N_2O emissions. Soil samples characterizing Turkish agricultural land were fertilized with varying ratios of conventional urea and NBPT-inhibited urea under controlled laboratory incubation experiments. Nitrate levels were analyzed to evaluate nitrogen transformation processes, and N_2O emissions were quantified using gas chromatography. The research aimed to identify the optimum blending ratios of fertilizers (%100 urea, %25 urea - %75 inhibited urea, %50 urea - %50 inhibited urea, %75 urea - %25 inhibited urea, and %100 inhibited urea) that minimize N_2O emissions while maintaining soil fertility. Preliminary findings, consistent with existing literature, indicate that inhibited fertilizers can reduce N_2O emissions by up to 87%, depending on soil type, moisture levels, and application methods. Experimental results demonstrated that the %50-%50 combination represents the optimal fertilization strategy.

This research underscores the importance of precision fertilization in sustainable agricultural practices. By optimizing fertilizer composition and application techniques, the study plays a vital role in developing nitrogen management strategies that support environmental sustainability and public health. These findings are expected to contribute to climate change mitigation efforts, promote sustainable land use, and inform the development of agricultural policy.

Keywords: Urease inhibitor; nitrous oxide emissions; nitrogen fertilizers; soil nitrogen dynamics; sustainable agriculture

ANSELM KIEFER'İN SANATINDA MALZEMENİN DÖNÜŞÜMÜ: ATIK, BELLEK VE ESTETİK ANLAM ÜRETİMİ

THE TRANSFORMATION OF MATERIAL IN ANSELM KIEFER'S ART: WASTE MEMORY, AND THE PRODUCTION OF AESTHETIC MEANING

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Özet
XX. yüzyılın ikinci yarısından itibaren çağdaş sanatta malzeme, yalnızca biçimsel bir üretim aracı olmaktan çıkarak tarihsel, kültürel ve düşünsel anlamların inşa edildiği temel bir ifade alanına dönüşmüştür. Sanatçılar bu süreçte geleneksel estetik anlayışını sorgulayarak doğal, endüstriyel ve kullanım dışı bırakılmış malzemeleri yeniden yorumlamış, söz konusu malzemeleri bellek, kimlik, savaş, yıkım ve yeniden yapılanma gibi kavramlarla ilişkilendirerek sanatın anlatım olanaklarını genişletmiştir. Bu dönüşümün önde gelen temsilcilerinden Anselm Kiefer, kurşun, kül, saman, toprak, beton, paslanmış metal, yanmış kitaplar ve çeşitli organik malzemeleri yalnızca fiziksel nitelikleri doğrultusunda değil, taşıdıkları tarihsel, kültürel ve simgesel yükler üzerinden sanat pratiğine dâhil etmektedir. Böylece malzeme, sanatçının yapıtlarında estetik bir unsur olmanın ötesinde kolektif belleğin, tarihsel travmaların ve kültürel sürekliliğin görünür kılındığı kavramsal bir taşıyıcı niteliği kazanmaktadır.
Bu araştırmanın amacı, Anselm Kiefer'in sanatında malzemenin dönüşümünü atık, bellek ve estetik anlam üretimi bağlamında incelemektir. Araştırmada nitel araştırma yöntemi benimsenmiş, sanat tarihi, çağdaş sanat kuramı ve görsel analiz yaklaşımları birlikte kullanılarak sanatçının seçilmiş yapıtları malzeme kullanımı, kavramsal içerik ve estetik yapı açısından değerlendirilmiştir. İnceleme sonucunda, Kiefer'in malzeme kullanımının yalnızca biçimsel bir yaratım stratejisi olmadığı, tarihsel yıkımın izlerini görünür kılan, nesnelere yeni anlamsal katmanlar kazandıran ve izleyiciyi bellek ile tarih arasındaki diyalektik ilişki üzerine düşünmeye yönlendiren çok katmanlı bir anlatım sistemi oluşturduğu belirlenmiştir. Bu çerçevede, atık ve kullanım dışı bırakılmış malzemelerin çağdaş sanatta yalnızca yeniden işlevlendirilen fiziksel nesneler olarak değil, kültürel hafızayı taşıyan, estetik anlam yaratan ve sanatın eleştirel söylemini derinleştiren kavramsal araçlar olarak değerlendirildiği ortaya konulmaktadır. Sonuç olarak çalışma, Anselm Kiefer'in sanatında malzemenin fiziksel dönüşümünden çok, tarihsel deneyimin, kolektif belleğin ve estetik düşüncenin yeniden inşasını mümkün kılan bir anlam yaratım mekanizması olarak işlediğini ileri sürmektedir. Bu yönüyle araştırma, çağdaş sanatta malzeme kuramı, dönüşüm estetiği ve bellek çalışmaları arasındaki disiplinlerarası ilişkiye katkı sunmayı, Kiefer'in yaratım pratiğini nesnenin maddesel özelliklerinden ziyade malzemenin tarihsel, kültürel ve kavramsal potansiyeli üzerinden değerlendiren bütüncül bir okuma önermeyi amaçlamaktadır.
Anahtar Kelimeler: Anselm Kiefer, Çağdaş Sanat, Malzemenin Dönüşümü, Atık, Bellek, Estetik Anlam Yaratımı.

Abstract
Since the second half of the twentieth century, material in contemporary art has evolved beyond being merely a formal medium of production into a fundamental mode of expression through which historical, cultural, and intellectual meanings are constructed. During this period, artists challenged conventional aesthetic paradigms by reinterpreting natural, industrial, and discarded materials, associating them with concepts such as memory, identity, war, destruction, and reconstruction, thereby expanding the expressive possibilities of artistic practice. As one of the leading representatives of this transformation, Anselm Kiefer incorporates materials including lead, ash, straw, earth, concrete, corroded metal, burned books, and various organic substances into his artistic practice not only for their physical properties but also for the historical, cultural, and symbolic meanings they embody.

Consequently, material in Kiefer's works functions beyond a purely aesthetic element, becoming a conceptual vehicle through which collective memory, historical trauma, and cultural continuity are articulated.

This study aims to examine the transformation of material in Anselm Kiefer's artistic practice within the framework of waste, memory, and the production of aesthetic meaning. Employing a qualitative research methodology, the study integrates art historical inquiry, contemporary art theory, and visual analysis to examine selected works by the artist in terms of materiality, conceptual content, and aesthetic structure. The findings demonstrate that Kiefer's use of materials extends beyond a formal strategy of artistic production; instead, it constitutes a multilayered visual language that renders the traces of historical destruction visible, endows objects with new semantic dimensions, and encourages viewers to reconsider the dialectical relationship between memory and history. Within this context, the study argues that discarded and abandoned materials in contemporary art should be understood not merely as physically repurposed objects but as conceptual agents that embody cultural memory, generate aesthetic meaning, and deepen the critical discourse of artistic practice.

In conclusion, the study contends that in Kiefer's oeuvre, the transformation of material functions less as a process of physical alteration than as a mechanism for reconstructing historical experience, collective memory, and aesthetic thought. Accordingly, the research contributes to the interdisciplinary dialogue between material theory, the aesthetics of transformation, and memory studies in contemporary art while proposing a holistic interpretation of Kiefer's artistic practice that emphasizes the historical, cultural, and conceptual potential of materiality rather than its merely physical characteristics.

Keywords: Anselm Kiefer, Contemporary Art, Material Transformation, Waste, Memory, Aesthetic Meaning Production.

RAPID PHOTOCATALYTIC DEGRADATION OF AZO DYES USING TİVALC MAX PHASE

TİVALC MAX FAZI İLE AZO BOYALARIN HIZLI FOTOKATALİTİK BOZUNMASI

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ABSTRACT
The discharge of synthetic dyes into aquatic environments is considered an important environmental problem due to their intense color, complex molecular structures, and resistance to conventional treatment methods. Photocatalytic degradation has received increasing attention in organic pollutant removal because it enables the decomposition of complex organic molecules under light irradiation with relatively simple operation and low cost. The efficiency of this process is closely related to the structural and physicochemical properties of the photocatalyst. Therefore, the development of alternative photocatalytic materials remains important. MAX phases, characterized by their layered crystal structure and the coexistence of metallic and ceramic properties, have drawn interest as functional materials for photocatalytic applications. In this study, the TiVAlC MAX phase was employed for the degradation of two anionic azo dyes, Acid Orange 7 and Acid Red 17. Photocatalytic experiments were conducted for both dyes at an initial concentration of 15 mg/L in the presence of 0.1 mmol/L peroxymonosulfate, with a reaction time of 40 min. Under these conditions, degradation efficiencies of 83.2% and 96.4% were obtained for Acid Orange 7 and Acid Red 17, respectively. The higher degradation efficiency obtained for Acid Red 17 may be associated with differences in the molecular structure and chemical reactivity of the dyes. The results also indicate that a short reaction time and a low peroxymonosulfate concentration were sufficient to achieve notable degradation of both pollutants. Overall, the TiVAlC MAX phase showed effective performance in the degradation of anionic azo dyes and may be considered a suitable photocatalyst for the treatment of dye-containing water.
Keywords: Photocatalytic degradation, TiVAlC MAX phase, Dye removal.

ÖZET
Sentetik boyaların sucul ortamlara deşarjı; yoğun renkleri, karmaşık moleküler yapıları ve geleneksel arıtma yöntemlerine karşı dirençleri nedeniyle önemli bir çevre sorunu olarak kabul edilmektedir. Fotokatalitik bozunma, nispeten basit bir işletim ve düşük maliyetle, ışık ışınımı altında karmaşık organik moleküllerin parçalanmasını sağladığı için organik kirleticilerin gideriminde giderek artan bir ilgi görmektedir. Bu sürecin verimliliği, fotokatalizörün yapısal ve fizikokimyasal özellikleriyle yakından ilişkilidir. Bu nedenle, alternatif fotokatalitik malzemelerin geliştirilmesi önemini korumaktadır. Tabakalı kristal yapıları ile metalik ve seramik özelliklerin bir arada bulunmasıyla karakterize edilen MAX fazları, fotokatalitik uygulamalar için işlevsel malzemeler olarak ilgi çekmektedir. Bu çalışmada, TiVAlC MAX fazı iki anyonik azo boyanın, Asit Oranj 7 ve Asit Kırmızı 17'nin bozunması için kullanılmıştır. Fotokatalitik deneyler, her iki boya için 15 mg/L başlangıç konsantrasyonunda, 0,1 mmol/L peroksimonosülfat varlığında ve 40 dakikalık reaksiyon süresinde gerçekleştirilmiştir. Bu koşullar altında, Asit Turuncu 7 ve Asit Kırmızı 17 için sırasıyla %83,2 ve %96,4 bozunma verimleri elde edilmiştir. Asit Kırmızı 17 için elde edilen daha yüksek bozunma verimi, boyaların moleküler yapısı ve kimyasal reaktivitesindeki farklılıklarla ilişkili olabilir. Sonuçlar ayrıca, her iki kirleticinin de kayda değer ölçüde bozunmasını sağlamak için kısa bir reaksiyon süresinin ve düşük bir peroksimonosülfat konsantrasyonunun yeterli olduğunu göstermektedir.

Genel olarak, TiVAlC MAX fazı anyonik azo boyaların bozunmasında etkili bir performans göstermiş ve boya içeren suların arıtımı için uygun bir fotokatalizör olarak değerlendirilebilir.

Anahtar Kelimeler: Fotokatalitik bozunma, TiVAlC MAX fazı, Boya giderimi.

BUGÜN NAKİT, SONRA PERFORMANS: GELİŞEN BİR EKONOMİDE GECİKMEYE BAĞLI PANEL NEDENSELLİK KANITLARI

TODAY CASH, PERFORMANCE LATER: EVIDENCE OF PANEL CAUSALITY DUE TO LAG IN AN EMERGING ECONOMY

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ÖZET
Bu çalışma, kurumsal nakit bulundurma düzeylerinin firma değerini hangi gecikmelerde nedensel olarak öngördüğünü araştırmaktadır. Analiz, Borsa İstanbulda faaliyet gösteren firmalar üzerinde 2005–2023 dönemine ait yıllık verilerine dayanarak 1691 gözlemle gerçekleştirilmiştir. Tanımlayıcı istatistik bulguları, ortalama firma değeri Q değerinin 1,47, Cash/TA oranının %8 ve Cash/CA oranının %15 olduğunu göstermektedir. Panel Granger nedenselliği önce Dumitrescu–Hurlin (2012) testiyle, ardından yarım panel jackknife düzeltmeli Juodis–Karavias–Sarafidis (2021) testiyle incelenmiştir. Sağlam JKS sonuçları, her iki nakit göstergesinden TobinQ'ya doğru nedenselliğin birinci ve ikinci gecikmelerde bulunmadığını, yalnızca üçüncü gecikmede güçlü biçimde ortaya çıktığını göstermektedir. Bu bulgu, nakit politikalarının firma değerine etkisinin anlık değil, gecikmeli olduğunu ortaya koymaktadır. Kontrol değişkenlerinde de belirgin bir zamanlama yapısı vardır: maddi duran varlıklar birinci; büyüme ve sermaye harcamaları ikinci ve üçüncü; nakit akışı üçüncü gecikmede firma değerinin Granger nedenidir. Maddi olmayan varlıklar ile COVID-19 şoku bütün gecikmelerde etkiliyken, kaldıraç birinci ve üçüncü, finansal kriz ise ikinci ve üçüncü gecikmelerde nedensellik göstermektedir. Dumitrescu–Hurlin testinin daha yaygın retler üretmesine karşılık JKS testinin daha seçici bulgular vermesi, dinamik panel nedensellik analizlerinde yanlılık düzeltmesinin önemini göstermektedir. Sonuçlar, yöneticilerin nakit kararlarını kısa vadeli piyasa tepkileriyle değerlendirmemesi ve değer etkisini daha uzun bir zaman ufkunda izlemesi gerektiğine işaret etmektedir.
Anahtar Kelimeler: Nakit bulundurma, Firma değeri, Panel Granger nedensellik

ABSTRACT
This study investigates the lags at which corporate cash-holding levels causally predict firm value. The analysis is conducted using 1,691 annual firm-year observations for firms listed on Borsa Istanbul over the 2005–2023 period. Descriptive statistics indicate that the mean firm value, measured by Tobin's Q, is 1.47, while the mean Cash/TA and Cash/CA ratios are 8% and 15%, respectively. Panel Granger causality is first examined using the Dumitrescu–Hurlin (2012) test and subsequently through the half-panel jackknife-corrected Juodis–Karavias–Sarafidis (2021) test. The robust JKS results reveal no causality from either cash-holding measure to Tobin's Q at the first or second lag; strong causality emerges only at the third lag. This finding demonstrates that the effect of cash policies on firm value is delayed rather than immediate. A distinct temporal pattern also emerges among the control variables: tangible assets Granger-cause firm value at the first lag; growth and capital expenditures at the second and third lags; and cash flow at the third lag. Intangible assets and the COVID-19 shock exhibit causality at all lags, whereas leverage shows causality at the first and third lags and the financial crisis at the second and third lags. While the Dumitrescu–Hurlin test produces more widespread rejections of the non-causality hypothesis, the more selective findings of the JKS test underscore the importance of bias correction in dynamic panel causality analyses. The results suggest that managers should not assess cash decisions solely through short-term market reactions but should evaluate their value implications over a longer time horizon.
Keywords: Cash holdings, Firm value, Panel Granger causality

TIME-FREQUENCY DYNAMICS OF ENERGY INTENSITY IN TÜRKIYE: GROWTH, URBANIZATION, AND FINANCIAL DEVELOPMENT – WAVELET COHERENCE APPROACH

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ÖZET
Bu çalışma, Türkiye'de 1970-2022 döneminde enerji yoğunluğu ile üç temel makroekonomik belirleyici ekonomik büyüme, kentleşme ve finansal gelişme- arasındaki zamana bağlı değişen ilişkiyi incelemektedir. Kişi başına GSYİH, kentsel nüfus payı, özel sektöre açılan yerel krediler ve enerji yoğunluğu (GSYİH birimi başına enerji kullanımı) değişkenlerine ait yıllık veriler kullanılarak, bu ilişkilerin zaman ve frekans boyutunda birlikte nasıl evrildiğini ortaya koymak amacıyla sürekli dalgacık dönüşümü, çapraz dalgacık analizi ve dalgacık uyumluluk (wavelet coherence) yöntemleri uygulanmıştır. Dalgacık uyumluluk analizi, GSYİH ile enerji yoğunluğu arasında güçlü, istatistiksel olarak anlamlı ve ağırlıklı olarak ters fazlı bir ilişki olduğunu göstermektedir; bu ilişki 2000 sonrasında 4-8 yıllık periyotta yoğunlaşmıştır: daha hızlı büyüme dönemleri, azalan enerji yoğunluğu ile ilişkilendirilmektedir. Kentleşme, örneklemin büyük bölümünde enerji yoğunluğu ile zayıf ve büyük ölçüde anlamsız bir uyum göstermekte, yalnızca son yıllarda güçlenmektedir; bu durum, Türkiye'nin kentleşme sürecinin hâlâ devam etmekte olduğu gerçeğiyle tutarlıdır. Finansal gelişme ise 2000 yılından bu yana enerji yoğunluğu ile orta düzeyde pozitif bir birlikte hareket sergilemekte ve orta vadeli döngülerde yoğunlaşmaktadır. Bu sonuçlar, Türkiye'de enerji-büyüme ilişkisinin gerçek olmakla birlikte, istikrarlı ve zamandan bağımsız bir ilişkiden ziyade belirli zaman aralıkları ve frekanslara özgü olduğunu göstermektedir; bu durum enerji verimliliği ve kentsel planlama politikalarının zamanlaması ve hedeflenmesi açısından doğrudan sonuçlar taşımaktadır.
Anahtar Kelimeler: enerji yoğunluğu; dalgacık uyumluluğu; zaman-frekans analizi; ekonomik büyüme; kentleşme; finansal gelişme; ARDL sınır testi; Türkiye

ABSTRACT
This study examines the time-varying relationship between energy intensity and three key macroeconomic drivers—economic growth, urbanization, and financial development—in Türkiye between 1970 and 2022. Using annual data on GDP per capita, urban population share, local credit to the private sector, and energy intensity (energy use per unit of GDP), continuous wavelet transformations, cross-wavelet analysis, and wavelet coherence were applied to characterize how these relationships evolved together over time and frequency. Wavelet coherence reveals a strong, statistically significant, and predominantly inverse-phase relationship between GDP and energy intensity; this relationship intensified in the 4-8 year period after 2000: periods of faster growth are associated with declining energy intensity. Urbanization shows a weak, largely insignificant coherence with energy intensity across the majority of the sample, strengthening only in recent years; This is consistent with the fact that Türkiye's urbanization process is still ongoing. Financial development has shown a moderately positive co-movement with energy intensity since 2000 and is concentrated in medium-term cycles. These results show that the energy-growth relationship in Türkiye is real, but rather localized to specific time intervals and frequencies rather than a stable, time-independent relationship; this has direct implications for the timing and targeting of energy efficiency and urban planning policies.
Keywords: energy intensity; wavelet coherence; time-frequency analysis; economic growth; urbanization; financial development; ARDL bounds test; Turkey

SIMULATION STUDY ON NANOFILTRATION PRETREATMENT IN SEAWATER REVERSE OSMOSIS DESALINATION USING WAVE® SOFTWARE

DENİZ SUYU TERS OZMOZ DESALİNASYONUNDA NANOFİLTRASYON ÖN ARITMASININ WAVE® YAZILIMI İLE SİMÜLASYON ÇALIŞMASI

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ÖZET

Küresel olarak artan nüfus ile birlikte tatlı su talebi artmakta, buna bağlı olarak alternatif su kaynakları arayışı oluşmaktadır. Bu sebeple deniz suyu desalinasyon kapasitesi hızla yükselmektedir. Membran bazlı Ters Ozmoz (RO) teknolojisi en yaygın yöntem olsa da yüksek işletme basıncı, yüksek enerji tüketimi ve ham deniz suyundaki sertlik iyonlarının (Ca^{2+}, Mg^{2+}, SO_4^{2-}) neden olduğu membran kirlenmesi gibi ciddi teknik ve ekonomik kısıtlamalarla karşı karşıyadır. Bu çalışmada, SWRO sistemlerinde ön arıtma olarak farklı nanofiltrasyon (NF) membranlarının entegrasyonu; enerji verimliliği, membran alanı, iyon ayırma performansı ve toplam maliyet (CAPEX+OPEX) yönüyle DuPont WAVE® (Water Application Value Engine) yazılımı kullanarak simüle ve optimize edilmiştir. NF270 membranı %35, %50 ve %65 su geri kazanım oranlarında (WRR); NF90 membranı ise %35 ve %48 geri kazanım oranlarında test edilmiştir. Simülasyon sonuçları, NF270 membranının düşük işletme basıncı ve yüksek akı özellikleri sayesinde NF90'a kıyasla belirgin bir ekonomik üstünlük sağladığını göstermiştir. NF270 membranının geri kazanım oranı %35'ten %65'e çıkarıldığında enerji tüketiminin 1,47 kWh/m³'ten 1,18 kWh/m³'e düştüğü, ancak ihtiyaç duyulan membran alanının 2621 m²'den 3108 m²'ye yükseldiği belirlenmiştir. NF90 membranı ise %48 geri kazanım oranında 2,62 kWh/m³ enerji tüketimi ve 4632 m² membran alanı gereksinimi göstermiştir. Ayrıca NF konsantre akımından su geri kazanımını artırmak ve atık hacmini azaltmak amacıyla kalsiyum (%98) ve magnezyumun (%99) kimyasal çöktürme ile uzaklaştırıldığı varsayımı altında ikincil bir SWRO ünitesi sürece dahil edilmiştir. Ekonomik analizler, %65 geri kazanım oranında çalışan NF270 konfigürasyonunun düşük enerji gereksinimi ve yüksek birim su verimliliği sunduğunu ortaya koymuştur. Bu kurulum, temiz su üretiminde metreküp başına yaklaşık 1.49 USD ile en düşük birim maliyeti sağlarken, NF90 konfigürasyonlarına kıyasla çok daha üstün bir ekonomik performans sergilemiştir. Ayrıca, çıkış suyu kalitesi açısından, NF270-RO50 entegre sistemlerinden elde edilen nihai toplam çözünmüş katı madde konsantrasyonları 372,45 mg/L ile 383,6 mg/L arasında değişerek hedeflenen içme suyu standartlarına oldukça yakın değerler vermiştir.

Anahtar Kelimeler: Nanofiltrasyon, Ters Ozmoz, Deniz Suyu Desalinasyonu, Ön Arıtma, Wave® Yazılımı.

ABSTRACT

Global population growth increses freshwater demand, expanding seawater desalination capacity worldwide. Although membrane-based Reverse Osmosis (RO) is the most common technology, it faces severe technical and economic challenges, including high operating pressure, high energy consumption, and membrane fouling/scaling caused by hardness ions (Ca^{2+}, Mg^{2+}, SO_4^{2-}) in raw seawater.

In this study, integrating different nanofiltration (NF) membranes as a pretreatment step in seawater reverse osmosis (SWRO) systems was simulated and optimized regarding energy efficiency, membrane area requirement, ion separation performance, and total cost (CAPEX+OPEX) using DuPont WAVE® software. In the simulations, the NF270 membrane was tested at water recovery rates (WRR) of 35%, 50%, and 65%, while the NF90 membrane was evaluated at 35% and 48%. Results revealed that NF270 exhibited a distinct economic advantage over NF90 due to its lower operating pressure and higher flux characteristics. Increasing the NF270 recovery rate from 35% to 65% reduced specific energy consumption from 1.47 kWh/m³ to 1.18 kWh/m³, while the required membrane area increased from 2621 m^2 to 3108 m^2. Conversely, the NF90 membrane required 2.62 kWh/m³ of energy and 4632 m^2 of membrane area at a 48% recovery rate. Furthermore, to enhance water recovery from the NF concentrate stream and reduce waste volume, a second SWRO unit was added assuming 98% calcium and 99% magnesium removal via chemical precipitation. Economic analyses demonstrated that the NF270 setup at 65% recovery achieved the lowest unit cost at approximately 1.49 USD/m^3 of product water, showing superior performance compared to NF90. Regarding product quality, the integrated NF270-RO50 systems yielded final total dissolved solids (TDS) levels between 372.45 mg/L and 383.6 mg/L, closely approaching target drinking water standards.

Keywords: Nanofiltration, Reverse Osmosis, Seawater Desalination, Pretreatment, Wave® Software.

YEŞİL FİNANS VE ENERJİ DÖNÜŞÜMÜNÜ ANLAMAK: ÇOK BOYUTLU BİR YAKLAŞIM

UNDERSTANDING GREEN FINANCE AND THE ENERGY TRANSITION: A MULTIDIMENSIONAL APPROACH

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ÖZET
Sürdürülebilir bir enerji sistemine geçiş süreci, uzun vadeli çevresel hedefleri destekleyebilecek finansal mekanizmaların önemini artırmıştır. Yeşil finans, hem akademik literatürde hem de politika tartışmalarında giderek daha fazla ilgi görmekle birlikte, farklı yeşil finans araçlarının enerji dönüşümüne farklı kanallar aracılığıyla katkı sağlayabileceği değerlendirilmektedir. Bu çalışma, çok boyutlu bir analitik çerçeve benimseyerek yeşil finansın farklı bileşenleri ile enerji dönüşümü arasındaki ilişkiyi incelemeyi amaçlamaktadır. Analiz kapsamında ihtiyati düzenlemeler, yönlendirilmiş yeşil krediler, sürdürülebilir finansman ilkeleri ve yeşil tahvil gelişimi olmak üzere yeşil finansın temel araçları ele alınmaktadır. Geniş bir dönemi kapsayan çeyreklik veriler kullanılarak, söz konusu değişkenler arasındaki etkileşimlerin farklı zaman ölçekleri ve dağılımsal koşullar altında incelenmesi amacıyla dalgacık (wavelet) tabanlı gelişmiş ekonometrik yöntemlerin uygulanması planlanmaktadır. Farklı politika araçlarını bütüncül bir ampirik çerçevede değerlendirmeyi hedefleyen bu araştırmanın, sürdürülebilir finans literatürüne katkı sağlaması ve enerji dönüşümünü destekleyecek alternatif politika tasarımlarının değerlendirilmesine yönelik bir temel oluşturması beklenmektedir.
Anahtar Kelimeler: Sürdürülebilir Finans, Enerji Dönüşümü, Yeşil Yatırımlar, Temiz Enerji, Finansal Araçlar

ABSTRACT
The transition toward a sustainable energy system has intensified the need for financial mechanisms capable of supporting long-term environmental objectives. Although green finance has attracted increasing attention in both academic and policy discussions, different financial instruments may contribute to the energy transition through distinct channels. This study explores the relationship between multiple dimensions of green finance and the energy transition by adopting a multidimensional analytical framework. The analysis considers several representative green finance instruments, including prudential regulations, directed green credit, sustainable financing principles, and green bond development. Using quarterly data over an extended sample period, the study plans to employ advanced wavelet-based econometric techniques to examine the interactions between these variables across different frequencies and distributional conditions. By integrating various policy instruments within a unified empirical framework, the research aims to contribute to the growing literature on sustainable finance and to provide a basis for evaluating alternative policy designs that support the transition toward cleaner energy systems.
Keywords: Sustainable Finance; Energy Policy; Green Investment; Clean Energy; Financial Instruments

BIBLIOMETRIC AND KNOWLEDGE MAPPING ANALYSIS OF SPATIAL TRANSCRIPTOMICS RESEARCH ON HOST–MICROBIOME INTERACTIONS (2018–2026)

KONAK–MİKROBİYOM ETKİLEŞİMLERİNDE UZAYSAL TRANSKRİPTOMİK ARAŞTIRMALARININ BİBLİYOMETRİK VE BİLGİ HARİTALAMA ANALİZİ (2018–2026)

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ABSTRACT
Spatial transcriptomics bridges transcriptomic profiling and tissue morphology by preserving the spatial coordinates of gene expression within histological architecture. In microbiome research, this approach can reveal not only which microorganisms are present, but also the cellular niches they occupy and the host programs associated with microbial proximity. This study evaluated the global literature combining spatial transcriptomics with microbiome, microbiota, bacteria, and pathogen concepts through bibliometric and knowledge-mapping methods. A total of 496 Web of Science Core Collection documents published between 2018 and 2026 were analyzed using Bibliometrix/Biblioshiny. The dataset comprised 5,229 authors and 261 sources, with an annual growth rate of 91.91%, 16.58 average citations per document, and 31.05% international co-authorship. Scientific production accelerated markedly after 2022. Nature Communications and Frontiers in Immunology were the most productive sources. China led publication output, whereas the United States received the highest total citations. The conceptual structure centered on spatial transcriptomics, pathogenesis, inflammation, single-cell RNA sequencing, cancer, macrophages, and the tumor microenvironment. Trend analysis indicated a shift from tissue mapping and gene expression toward mechanisms, cancer, and machine learning in 2025–2026. The field is rapidly expanding but still requires improved methodological standardization, microbial RNA capture sensitivity, contamination control, and histopathological validation.
Keywords: Spatial transcriptomics; microbiome; microbiota; histology; host–microbe interaction; bibliometric analysis

ÖZET
Uzaysal transkriptomik, gen ekspresyonunu histolojik mimari içindeki konumuyla birlikte değerlendirmeye olanak sağlayarak klasik transkriptomik ile doku morfolojisi arasındaki boşluğu kapatmıştır. Mikrobiyom araştırmalarında bu yaklaşım, mikroorganizmaların yalnızca hangi dokuda bulunduğunu değil, hangi hücresel nişlerde konumlandığını ve yakın çevredeki konak hücre programlarını nasıl etkilediğini çözümleme potansiyeline sahiptir. Bu çalışmada, uzaysal transkriptomik ile mikrobiyom, mikrobiyota, bakteri ve patojen kavramlarını birlikte ele alan küresel literatür bibliyometrik ve bilgi haritalama yöntemleriyle değerlendirilmiştir. Web of Science Core Collection'dan elde edilen 2018–2026 dönemine ait 496 doküman Bibliometrix/Biblioshiny aracılığıyla analiz edilmiştir. Veri seti 261 kaynakta yayımlanan, 5.229 yazarın katkı sunduğu çalışmalardan oluşmuştur; yıllık büyüme oranı %91,91, doküman başına ortalama atıf 16,58 ve uluslararası ortak yazarlık oranı %31,05 olarak belirlenmiştir. Yıllık üretim 2022 sonrasında keskin biçimde hızlanmış; Nature Communications ve Frontiers in Immunology en üretken kaynaklar olmuştur. Çin doküman sayısında, ABD ise toplam atıfta öne çıkmıştır. Kavramsal yapı; uzaysal transkriptomik, patogenez, inflamasyon, tek hücreli RNA dizileme, kanser, makrofajlar ve tümör mikroçevresi eksenlerinde yoğunlaşmıştır. Eğilim analizi, alanın erken dönemde doku haritalama ve gen ekspresyonundan 2025–2026 döneminde mekanizma, kanser ve makine öğrenmesi temalarına kaydığını göstermiştir.

Bulgular, alanın hızla büyüyen ancak yöntemsel standardizasyon, mikrobiyal RNA yakalama duyarlılığı, kontaminasyon kontrolü ve histopatolojik doğrulama açısından gelişime açık bir araştırma ekosistemi olduğunu göstermektedir.
Anahtar Kelimeler: Uzaysal transkriptomik; mikrobiyom; mikrobiyota; histoloji; konak–mikrop etkileşimi; bibliyometrik analiz

INTRODUCTION

One of the fundamental principles of tissue biology is that cellular behavior is determined not only by molecular composition but also by the interactions of cells with their neighboring cells, the extracellular matrix, and their anatomical location (Li et al., 2017). While conventional bulk RNA sequencing provides the average gene expression profile of a tissue, single-cell RNA sequencing reveals cellular heterogeneity; however, the original spatial context within the tissue is often lost (Longo et al., 2021). The spatial transcriptomics approach developed by Ståhl et al. (2016), using barcoded capture arrays on tissue sections, enabled RNA expression profiles to be analyzed within the same coordinate system as histological images, thereby integrating histology with molecular omics.

For many years, microbiome research has primarily relied on analyses of relative abundance and taxonomic diversity at the sample level (Human Microbiome Project Consortium, 2012; Li et al., 2012). Conventional microbiome analyses remain limited in revealing the spatial organization of microorganisms within tissues and their interactions with neighboring host cells. Recently developed technologies, including spatial host–microbiome sequencing, spatial metatranscriptomics, highly multiplexed fluorescence in situ hybridization (FISH), and related approaches, have enabled the simultaneous spatial mapping of host transcripts together with bacterial and fungal signals within the same histological section, thereby facilitating the investigation of tissue microniches and host–microbiome interactions in their spatial context (Cao et al., 2026; Galeano Niño et al., 2022; Lötstedt et al., 2024; Saarenpää et al., 2024).

The field is particularly relevant to tumor microbiome research, inflammatory bowel diseases, dermatological disorders, infection biology, and mucosal immunology. Galeano Niño et al. (2022) demonstrated that intratumoral bacteria are not randomly distributed within cancer tissues but are instead associated with specific cellular microniches, thereby contributing to the spatial and cellular heterogeneity of tumors. Using the SHM-seq approach, Lötstedt et al. (2024), together with the spatial metatranscriptomics method developed by Saarenpää et al. (2024), demonstrated that host–bacteria–fungi interactions in the gut can be investigated at micrometer-scale resolution. These technological advances provide a foundation for integrating histopathological findings with molecular and microbial context rather than limiting them to morphological description alone.

The rapid expansion of the literature necessitates a systematic evaluation of research actors, major themes, knowledge bases, and emerging trends. Bibliometrics quantitatively maps the scientific structure of a research field through publications, citations, co-authorship patterns, and keyword relationships. Bibliometrix and its web interface, Biblioshiny, integrate performance analysis and science mapping methods within a unified analytical workflow (Aria and Cuccurullo, 2017). The aim of the present study was to identify the growth dynamics, influential sources, authors, institutions, countries, conceptual clusters, and emerging research hotspots within the global literature at the intersection of spatial transcriptomics and the microbiome.

MATERIALS AND METHODS

Data source and search strategy: Bibliographic data were retrieved from the Web of Science Core Collection database on 6 August 2026. The following search query was used: TS=("spatial transcriptomics") AND TS=(microbiome OR microbiota OR bacteria OR pathogen)*

The search results were exported as full records together with cited references. According to the Biblioshiny report, the dataset comprised 496 documents published between 2018 and 2026. As the year 2026 had not yet been completed, publication counts for this year were not considered as representing a full annual output. Owing to the broad search strategy, studies related to bacterial spatial transcriptomics, intratumoral microorganisms, and pathogen responses, although representing distinct experimental contexts within microbiome research, were also included in the dataset and were taken into consideration during the interpretation of the results.

Bibliometric analysis

The data were analyzed using the Bibliometrix R package and its Biblioshiny interface (Aria and Cuccurullo, 2017). Performance analysis included annual scientific production, source, author, institution, and country productivity, together with total and average citation counts and the h-, g-, and m-indices. Science mapping analyses comprised keyword frequency, trend topics, thematic structure, co-authorship networks, and collaboration patterns. Author name homonymy and institutional name duplication were recognized as inherent limitations of bibliometric databases.

RESULTS

General characteristics of the dataset

The dataset consisted of 496 documents published across 261 sources. Of these documents, 481 were research articles, 14 were early access articles, and one was a book chapter. A total of 5,229 authors contributed to the literature, with only one single-authored publication, and the average number of co-authors per document was 12.5. The rate of international co-authorship was 31.05%. The average number of citations per document was 16.58, the total number of cited references was 27,401, and the annual growth rate was 91.91% (Table 1).

Table 1. Main bibliometric indicators of the dataset.

Indicator	Value
Timespan	2018–2026
Number of sources	261
Number of documents	496
Annual growth rate	91.91%
Average document age	1.19 years
Average citations per document	16.58
Total references	27,401
Keywords Plus	1,338
Author's keywords	1,242
Number of authors	5,229
Co-authors per document	12.5
International co-authorship	31.05%

Annual scientific production

The first publication was indexed in 2018, and the annual number of publications remained limited during the 2018–2021 period. The number of documents increased to 19 in 2022, 41 in 2023, 79 in 2024, and 161 in 2025. At the time of data retrieval, 184 documents had been indexed for 2026; however, since the year had not yet been completed, this value should not be directly compared with the publication output of completed years (Figure 1).

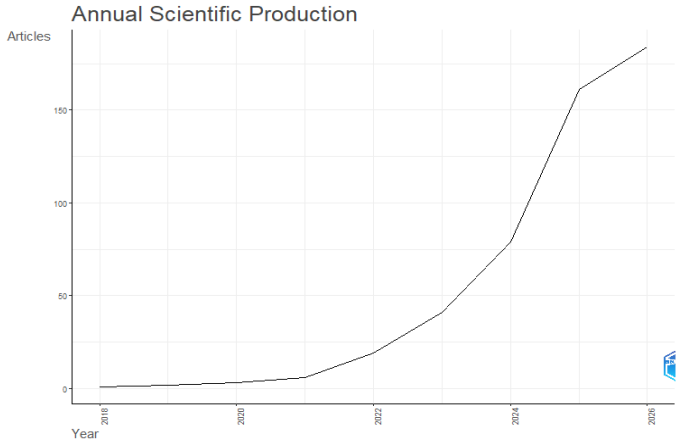


Figure 1. Annual scientific production in the spatial transcriptomics–microbiome literature.

Productivity and Impact of Sources

Nature Communications was the most productive source with 32 publications, followed by Frontiers in Immunology with 26 publications. Advanced Science, Journal of Translational Medicine, and JCI Insight were the subsequent most productive sources (Figure 2).

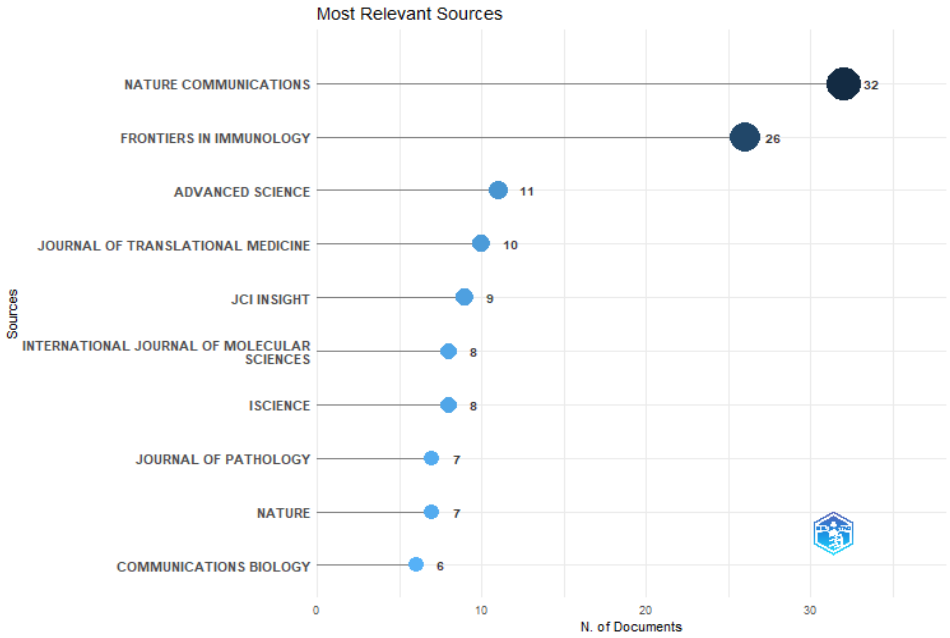


Figure 2. Top 10 most productive scientific sources.

Nature Communications was also the leading source in terms of local impact, with 32 publications, an h-index of 16, and 1,188 local citations. Although Nature published only seven articles, it accumulated 1,021 local citations, indicating that the field has been shaped by a relatively small number of highly influential studies (Table 2).

Table 2. Productivity and local impact indicators of the leading sources.

Source	Publications	h-index	Total local citations
Nature Communications	32	16	1,188
Frontiers in Immunology	26	6	96
Advanced Science	11	5	120
Journal of Translational Medicine	10	—	—
JCI Insight	9	5	90
Nature	7	6	1,021
iScience	8	4	58
Scientific Reports	6	4	131

Author and Institutional Productivity

Li Y (16 publications), Zhang Y (13 publications), and Chen Y (12 publications) were identified as the most productive authors (Table 3). However, because Web of Science records are based on author initials and surnames, there is a risk of homonymy, particularly for common Chinese surnames; therefore, these rankings should be interpreted with caution unless author identities have been disambiguated. In terms of local impact, Lundeberg J achieved 1,216 local citations, an h-index of 6, and six publications, reflecting a strong knowledge-base influence attributable to his pioneering methodological contributions to spatial transcriptomics.

Table 3. Most productive authors and selected local impact indicators.

Author	Publications	h-index	Local citations
Li Y	16	7	271
Zhang Y	13	7	179
Chen Y	12	3	62
Wang Y	9	—	—
Zhang Xy	9	—	—
Gudjonsson Je	8	5	334
Li J	8	5	95

At the institutional level, Harvard University ranked first with 87 publications, followed by the University of California System (66 publications), the University of Michigan (65 publications), and Central South University (47 publications) (Table 4). The presence of separate institutional records such as Harvard University, Harvard Medical Affiliates, and Harvard Medical School suggests that the actual institutional concentration may be greater than indicated by the individual entries presented in the table.

Table 4. Top 10 most productive institutions.

Institution	Publications
Harvard University	87
University of California System	66
University of Michigan	65
Central South University	47
University of Michigan System	46
Harvard Medical Affiliates	45
Sun Yat-sen University	45
Shanghai Jiao Tong University	39
University of Texas System	39
Harvard Medical School	38

Country Productivity, Impact, and Collaboration

According to the corresponding author's country, China ranked first in scientific production with 236 publications (47.58%), followed by the United States with 120 publications (24.19%). Only 13.98% of publications from China involved multiple-country collaboration, whereas the corresponding proportions were 35.00% for the United States, 65.00% for Germany, 73.68% for the United Kingdom, and 85.71% for Sweden. These findings indicate that China's publication output is characterized by a high volume of predominantly domestic collaborations, whereas European countries exhibit lower publication volumes but substantially stronger levels of international collaboration (Figure 3; Table 5).

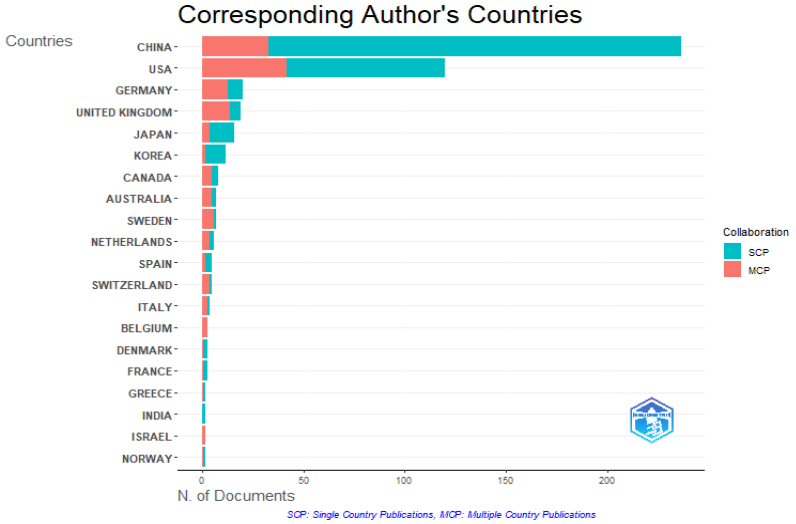


Figure 3. Top productive countries based on the corresponding author's affiliation.

Table 5. Distribution of single-country and multiple-country publications by corresponding author's country.

Country	Articles	SCP	MCP	MCP (%)
China	236	203	33	13.98
USA	120	78	42	35.0
Germany	20	7	13	65.0
United Kingdom	19	5	14	73.68
Japan	16	12	4	25.0
Korea	12	10	2	16.67
Canada	8	3	5	62.5
Australia	7	2	5	71.43
Sweden	7	1	6	85.71
Netherlands	6	2	4	66.67

In terms of total citations, the United States ranked first by a considerable margin with 3,832 citations. Although China ranked second with 1,662 citations, its average number of citations per article was 7.0. Belgium achieved an exceptionally high citation impact, with 711 total citations and an average of 237 citations per article, despite having only three corresponding-author publications, reflecting the effect of a small sample size. Therefore, both total citations and average citations per article should be considered when comparing countries.

Most Highly Cited Publications

The most highly cited publication in the dataset was the Nature article by Galeano Niño et al. (2022), which demonstrated the impact of the intratumoral microbiota on spatial and cellular heterogeneity in cancer, receiving 741 total citations and 148.2 citations per year. The Cell article by Chen et al. (2020), which used spatial transcriptomics and *in situ* sequencing to characterize cellular and molecular alterations surrounding amyloid plaques in Alzheimer's disease, ranked among the most influential publications in the dataset with 679 global citations. These findings indicate that the field has been driven primarily by highly influential applications revealing cellular niches and disease mechanisms in clinical tissues rather than by bioinformatics methodologies (Table 6).

Table 6. Top eight globally cited publications.

Study	DOI	Total citations	Annual citations
Galeano Niño et al., Nature, 2022	10.1038/s41586-022-05435-0	741	148.2
Chen et al., Cell, 2020	10.1016/j.cell.2020.06.038	679	97.0
Theocharidis et al., Nat Commun, 2022	10.1038/s41467-021-27801-8	338	67.6
Maniatis et al., Science, 2019	10.1126/science.aav9776	329	41.1
Joshi et al., Eur Respir J, 2020	10.1183/13993003.00646-2019	264	37.7
Dar et al., Science, 2021	10.1126/science.abi4882	239	39.8
Ma et al., Nat Commun, 2023	10.1038/s41467-023-39020-4	229	57.2
Andrews et al., J Hepatol, 2024	10.1016/j.jhep.2023.12.023	134	44.7

Keywords and Conceptual Structure

The most frequently used term was "spatial transcriptomics", which appeared 143 times. It was followed by expression (118 occurrences), pathogenesis (64), inflammation (51), cells (50), and activation (44). The terms single-cell RNA sequencing and gene expression each appeared 39 times. Keywords such as cancer, macrophages, T cells, tumor microenvironment, and multi-omics indicate that the field is organized around the histological microenvironment, immunity, and disease mechanisms (Figure 4).

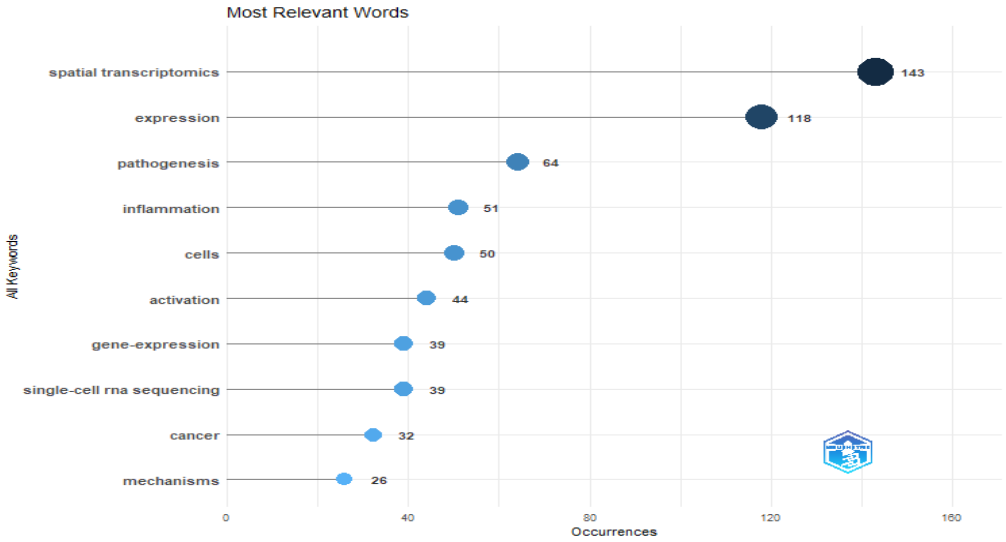


Figure 4. Most frequently occurring terms in the dataset.

The thematic map demonstrated that the main cluster centered on spatial transcriptomics encompassed concepts such as pathogenesis, gene expression, single-cell RNA sequencing, tumor microenvironment, heterogeneity, and cell migration within the same conceptual core. In the conceptual synthesis, spatial transcriptomics was identified as a motor theme with high centrality and density, whereas the tumor microenvironment and host–microbiome interactions emerged as basic/transversal themes, and machine learning was positioned as an emerging theme (Figure 5).

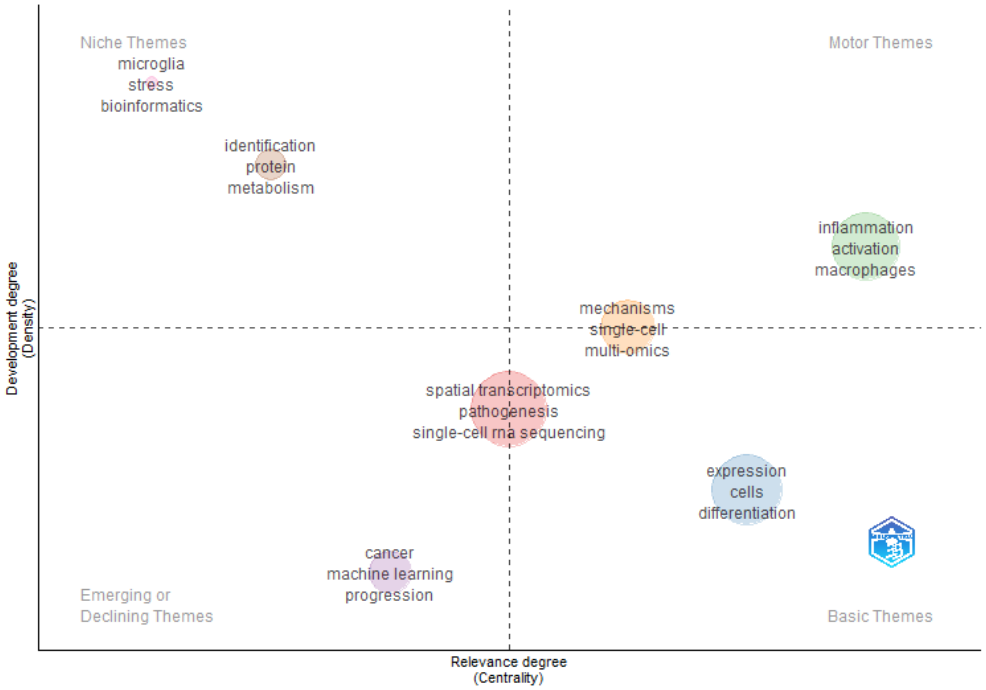


Figure 5. Conceptual thematic synthesis based on the Biblioshiny thematic analysis.

Trend Topics

Trend topic analysis showed that the terms brain, gene expression, T cells, and protein were prominent during the 2023–2024 period, whereas spatial transcriptomics, expression, and pathogenesis reached their median year in 2025. The median year for cancer, mechanisms, and machine learning was 2026. This shift indicates that the field has progressed from method development and atlas generation toward disease-specific mechanistic investigations and computational prediction (Figure 6).

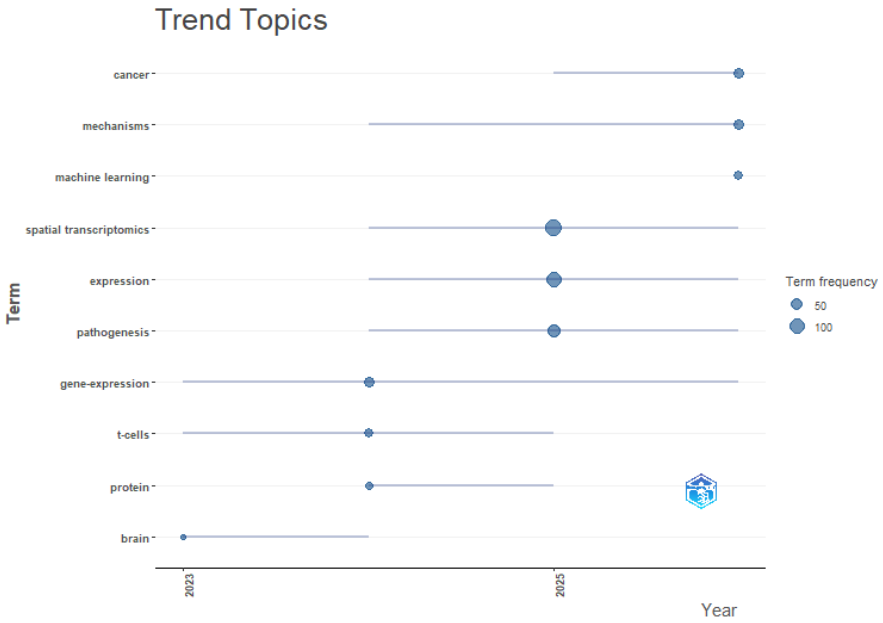


Figure 6. Distribution of trend topics according to their median years.

DISCUSSION

This bibliometric analysis demonstrates that the intersection of spatial transcriptomics and microbiome research represents an emerging research field that appeared after 2018 and has expanded rapidly since 2022. The annual growth rate of 91.91% reflects not only the increasing scientific interest in the field but also the widespread adoption of commercial platforms such as 10x Visium, the maturation of single-cell data integration tools, and the development of novel protocols capable of identifying microbial signals within spatial transcriptomic datasets. The original spatial transcriptomics method introduced by Ståhl et al. (2016) constituted a major methodological breakthrough by integrating tissue architecture with molecular mapping. However, because conventional protocols primarily target polyadenylated eukaryotic mRNA, the direct capture of bacterial RNA remains limited. To overcome this limitation, recently developed approaches such as SHM-seq and spatial metatranscriptomics have introduced specialized capture and analytical strategies that enable the simultaneous detection of host and microbial transcripts within the same histological section (Lötstedt et al., 2024; Saarenpää et al., 2024).

The prominence of journals such as Nature Communications and Nature in terms of both productivity and local impact indicates that the field has been driven by highly influential studies integrating technological innovation with disease biology. The highly cited spatial transcriptomics analyses conducted by Galeano Niño et al. (2022) demonstrated that intratumoral bacteria exhibit a heterogeneous spatial distribution within the tumor microenvironment and that bacteria-associated tumor cells display distinct transcriptional programs. These findings suggest that microbiome research has shifted beyond merely characterizing microbial composition toward identifying the spatial localization of microorganisms within tissues, determining the host cell types with which they interact, and elucidating the molecular responses associated with these interactions.

Gut tissues constitute a natural model for investigating the spatial organization of host–microbiome interactions. The mucus layer, crypt–villus axis, lamina propria, and lymphoid structures exhibit marked histological and microbial heterogeneity. Lötstedt et al. (2024) simultaneously analyzed host and microbial transcripts in the mouse intestine and demonstrated that distinct microbial communities are associated with specific spatial niches characterized by unique host transcriptional programs. Using a spatial metatranscriptomics approach, Saarenpää et al. (2024) simultaneously profiled host, bacterial, and fungal transcripts within the same spatial context, enabling tissue-level mapping of host–bacteria–fungi interaction networks. Furthermore, Jang et al. (2025) developed a spatial host–microbiome profiling strategy for Crohn's disease, revealing the distribution of invasive bacteria within intestinal tissues and their association with localized immune activation, thereby highlighting the translational potential of these technologies for clinical histopathology.

The prominence of keywords related to inflammation, T cells, macrophages, and immune activation in the bibliometric analysis indicates that the field is strongly centered on immunohistological research. These findings are consistent with the study of Galeano Niño et al. (2022), which demonstrated that the intratumoral microbiota shapes the spatial and cellular heterogeneity of tumor tissues, as well as with the findings of Li et al. (2024), who showed that microbial–T cell interactions influence the tumor immune microenvironment in pancreatic cancer. Taken together, these studies demonstrate that spatial transcriptomics and multimodal immune profiling approaches make important contributions to revealing the spatial organization of host–microbiome interactions within tissues and their relationships with the immune microenvironment at high resolution.

Country-level analysis identified China as the leading contributor in terms of publication output, whereas the United States showed the greatest overall citation impact and international influence. The relatively low multiple-country publication (MCP) rate of 13.98% among corresponding-author publications from China suggests that research productivity has largely been driven by domestic collaborative networks. In contrast, the higher levels of international collaboration observed in countries such as the United Kingdom, Germany, Sweden, and Switzerland are consistent with the multidisciplinary infrastructure required for advanced spatial omics research, integrating biobanking, pathology, microbiology, genomics, and computational sciences. The high average number of co-authors per publication further supports the interdisciplinary nature of this research field.

Contamination represents one of the principal methodological challenges in this field. In tissues with low microbial biomass, environmental, reagent-derived, or laboratory-derived DNA/RNA signals may mimic the authentic tissue microbiota. Therefore, orthogonal validation approaches—including negative controls, blank capture areas, tissue-specific fluorescence *in situ* hybridization (FISH), immunohistochemistry, culture, and targeted PCR—are essential. Inferring microbial presence solely from sequencing data may lead to false-positive findings, particularly in low-biomass specimens such as tumors and the placenta. In this context, histological localization represents not merely a visual confirmation but a fundamental component of biological validation.

The simultaneous analysis of host and microbial transcripts presents considerable technical challenges because of the low abundance of microbial RNA, the predominance of host RNA, and the distinct experimental processing requirements of different microorganisms. Although recently developed approaches, including SHM-seq, spatial metatranscriptomics, and highly multiplexed FISH-based technologies, have introduced novel experimental and computational strategies for detecting microbial signals with spatial resolution, further efforts are still required to improve methodological standardization and cross-platform comparability (Cao et al., 2026; Lötstedt et al., 2024; Saarenpää et al., 2024). Because each spot in spot-based spatial transcriptomics platforms may contain transcripts derived from multiple cell types, estimating the cellular composition underlying mixed gene expression signals has become a critical computational step. Cell2location was developed to estimate the abundance and spatial distribution of fine-grained cell types in spatial transcriptomics data by using cell-type reference profiles derived from single-cell RNA sequencing datasets (Kleshchevnikov et al., 2022). For the integration of single-cell datasets generated from different samples, experiments, and technologies, the anchor-based strategy implemented in Seurat enables the identification and integration of shared cellular states across datasets (Stuart et al., 2019). Similarly, the Harmony algorithm integrates multiple single-cell RNA sequencing datasets into a shared low-dimensional representation while preserving biological variation and minimizing technical and experimental batch effects (Korsunsky et al., 2019). The Weighted Nearest Neighbor (WNN) approach developed by Hao et al. (2021) enables integrated analysis of multimodal single-cell datasets by jointly modeling the relative information contributed by different molecular modalities, such as RNA and surface protein expression, for each individual cell. Once cell types and cellular states have been identified, CellChat infers potential cell–cell communication networks by integrating ligand, receptor, and cofactor expression profiles from single-cell RNA sequencing data, thereby enabling quantitative analysis of intercellular communication (Jin et al., 2021). In addition, DESeq2 is one of the most widely used methods for differential gene expression analysis of RNA sequencing data, employing a negative binomial statistical model to moderate dispersion and fold-change estimates (Love et al., 2014). The high local citation counts of the studies by Hao, Korsunsky, Jin, Stuart, and Kleshchevnikov within the present dataset further support the central role of these computational methodologies in advancing the field.

Machine learning emerged as an emerging theme in 2026, indicating the increasing application of artificial intelligence for multimodal spatial data classification, microbial niche prediction, and clinical outcome prediction. Nevertheless, the performance of these models remains dependent on sample size, inter-center technical variability, and the quality of pathological annotations. In the future, without standardized tissue processing protocols, open sharing of raw data, common ontologies, and independent validation cohorts, models that appear highly accurate may demonstrate limited clinical generalizability. First, the systematic integration of spatial microbiome signals with routine histopathological lesions remains insufficient. Morphological regions, including cryptitis, granulomas, necrosis, dysplasia, the invasive tumor front, perivascular inflammation, and fibrosis, should be annotated using standardized criteria, and transcriptomic and microbial data should be compared within these defined tissue regions. Second, most studies have employed cross-sectional designs; therefore, longitudinal investigations are needed to evaluate spatial alterations throughout disease progression and treatment response. Third, the simultaneous assessment of fungal, viral, and archaeal components alongside bacteria remains limited. Fourth, the viability and functional activity of tissue-associated microorganisms are often not directly demonstrated. Fifth, integrating single-cell resolution, true species-level identification, and FFPE compatibility within a single experimental protocol remains an important technical objective.

This analysis was based exclusively on records retrieved from the Web of Science Core Collection; therefore, publications indexed in Scopus, PubMed, and Dimensions were not included. The use of the search terms bacteria and pathogen* may have captured studies on infection biology, bacterial transcriptomics, and host–pathogen interactions in addition to conventional microbiome research. Conversely, restricting the search to the term "spatial transcriptomics" may have excluded studies that used terms such as spatial metatranscriptomics, SHM-seq, spatial microbiomics, or imaging-based spatial omics in their titles or abstracts without explicitly mentioning "spatial transcriptomics." Because data collection was performed before the completion of 2026, publication productivity and citation indicators for this year do not fully represent the final annual performance. Furthermore, homonymy among author names and inconsistencies in institutional name standardization remain inherent limitations. Since thematic maps are sensitive to the selected field, threshold values, and clustering algorithms, the results should be interpreted as a structural summary of the dataset rather than as absolute classifications.

CONCLUSION

The literature on spatial transcriptomics and the microbiome represents a rapidly expanding, highly interdisciplinary research field with substantial potential for clinical application during the 2018–2026 period. Scientific production accelerated markedly after 2022, with Nature Communications, Frontiers in Immunology, and other high-impact multidisciplinary journals serving as central channels of scientific dissemination. China led in publication output, whereas the United States had the greatest citation impact; meanwhile, European countries were distinguished by high levels of international collaboration.

The conceptual structure integrates spatial transcriptomics and single-cell analyses with pathogenesis, inflammation, cancer, macrophages, and the tumor microenvironment. The most highly cited studies demonstrated that microorganisms are not randomly distributed within tissues but are instead associated with distinct cellular niches. The shift in research trends toward mechanistic studies, cancer, and machine learning indicates that the field is evolving from descriptive atlases toward functional and translational models. Future research should emphasize robust histopathological annotation, orthogonal microbial validation, contamination control, cell- and species-level resolution, and multicenter standardization. The genuine integration of histology and microbiology will enable spatial omics data to evolve beyond colorful tissue maps into reliable tissue-based models capable of elucidating disease mechanisms.

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IN VITRO ASSESSMENT OF THE ANTIMICROBIAL ACTIVITY OF NATURAL BIOACTIVE COMPOUNDS AGAINST PSEUDOMONAS AERUGİNOSA AND STAPHYLOCOCCUS AUREUS

DOĞAL BİYOAKTİF BİLEŞİKLERİN PSEUDOMONAS AERUGİNOSA VE STAPHYLOCOCCUS AUREUS ÜZERİNDEKİ ANTİMİKROBİYAL ETKİLERİNİN IN VITRO DEĞERLENDİRİLMESİ

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ABSTRACT

Antimicrobial resistance is a major global public health concern that has reduced the effectiveness of currently available antibiotics and increased the need for novel antimicrobial agents. Plant-derived natural compounds have attracted considerable attention because of their diverse biological activities and relatively low toxicity. This study evaluated the in vitro antibacterial activities of kaempferol and fisetin against *Pseudomonas aeruginosa* ATCC 27853 and those of kaempferol and betulinic acid against *Staphylococcus aureus* ATCC 29213.

Antimicrobial activity was assessed using the broth microdilution method according to Clinical and Laboratory Standards Institute (CLSI) guidelines. Serial two-fold dilutions (1024–0.5 µg/mL) of the tested compounds were prepared in Mueller–Hinton broth. Ciprofloxacin and vancomycin served as quality control antibiotics for *P. aeruginosa* and *S. aureus*, respectively. Because the intrinsic color of the natural compounds interfered with visual assessment of bacterial growth, optical density at 600 nm (OD_{600}) was used to quantify bacterial growth after correction with compound control wells. Minimum bactericidal concentration (MBC) was evaluated by subculturing aliquots from the microdilution wells onto agar media.

The MIC values of ciprofloxacin (0.25 µg/mL) and vancomycin (0.5 µg/mL) were within the CLSI quality control ranges, confirming the validity of the susceptibility testing. None of the tested natural compounds achieved complete inhibition of bacterial growth at concentrations up to 1024 µg/mL; therefore, MIC and MBC values could not be determined. At the highest concentration tested, fisetin and kaempferol inhibited the growth of *P. aeruginosa* by approximately 47% and 35%, respectively. Against *S. aureus*, betulinic acid and kaempferol produced approximately 88% and 61% growth inhibition, respectively. Kaempferol demonstrated greater inhibitory activity against the Gram-positive organism than against the Gram-negative organism.

Although kaempferol, fisetin, and betulinic acid did not exhibit complete antibacterial activity within the tested concentration range, they produced concentration-dependent growth inhibition, with betulinic acid showing the strongest effect against *S. aureus*. These findings suggest that these natural compounds may have potential as adjunctive antimicrobial agents and warrant further investigation using higher concentrations, multidrug-resistant clinical isolates, and combination therapies with conventional antibiotics.

Keywords: antimicrobial resistance; kaempferol; fisetin; betulinic acid; broth microdilution method

ÖZET

Antimikrobiyal direnç, mevcut antibiyotiklerin etkinliğini azaltan önemli bir küresel halk sağlığı sorunudur ve yeni antimikrobiyal ajanların geliştirilmesini gerekli kılmaktadır. Bitki kökenli doğal biyoaktif bileşikler, geniş biyolojik aktiviteleri ve nispeten düşük toksisiteleri nedeniyle umut verici alternatifler olarak öne çıkmaktadır. Bu çalışmada, kaempferol ve fisetinin *Pseudomonas aeruginosa* ATCC 27853 ile kaempferol ve betulinik asidin *Staphylococcus aureus* ATCC 29213 üzerindeki in vitro antibakteriyel etkileri değerlendirilmiştir.

Antimikrobiyal aktivite, Klinik ve Laboratuvar Standartları Enstitüsü (CLSI) önerilerine uygun olarak broth mikrodilüsyon yöntemiyle araştırılmıştır. Test edilen bileşikler Mueller–Hinton broth içerisinde

1024–0,5 µg/mL konsantrasyon aralığında iki kat seri dilüsyonlar hâlinde hazırlanmıştır. *P. aeruginosa* için siprofloksasin, *S. aureus* için ise vankomisin kalite kontrol antibiyotikleri olarak kullanılmıştır. Doğal bileşiklerin kendilerine özgü renkleri nedeniyle bakteri üremesi görsel olarak değerlendirilemediğinden, üreme OD_{600} ölçümleri ile belirlenmiş ve bileşik kontrol kuyucukları kullanılarak arka plan düzeltmesi yapılmıştır. Minimum bakterisidal konsantrasyon (MBK), mikrodilüsyon kuyucuklarından alınan örneklerin uygun besiyerlerine ekilmesiyle değerlendirilmiştir.
Siprofloksasinin *P. aeruginosa* ATCC 27853 için MİK değeri 0,25 µg/mL, vankomisinin *S. aureus* ATCC 29213 için MİK değeri ise 0,5 µg/mL olarak belirlenmiş ve her iki değer de CLSI kalite kontrol aralıkları ile uyumlu bulunmuştur. Test edilen doğal bileşiklerin hiçbiri 1024 µg/mL'ye kadar olan konsantrasyonlarda bakteri üremesini tamamen inhibe edemediğinden MİK ve MBK değerleri belirlenememiştir. En yüksek test konsantrasyonunda fisetin ve kaempferol, *P. aeruginosa* üremesini sırasıyla yaklaşık %47 ve %35 oranında inhibe ederken; betulinik asit ve kaempferol, *S. aureus* üremesini sırasıyla yaklaşık %88 ve %61 oranında inhibe etmiştir. Kaempferolün Gram pozitif *S. aureus* üzerinde Gram negatif *P. aeruginosa*'ya kıyasla daha yüksek inhibitör etki gösterdiği belirlenmiştir.
Kaempferol, fisetin ve betulinik asit, çalışmada değerlendirilen konsantrasyon aralığında tam antibakteriyel etki göstermemiş ve bu nedenle MİK ile MBK değerleri belirlenememiştir. Bununla birlikte, betulinik asidin *S. aureus* ve fisetinin *P. aeruginosa* üzerindeki belirgin, konsantrasyona bağlı inhibitör etkileri bu doğal bileşiklerin tek başına bakterisidal ajanlardan ziyade yardımcı antimikrobiyal ajanlar olarak değerlendirilebileceğini düşündürmektedir. Bu bileşiklerin terapötik potansiyelinin daha iyi ortaya konulabilmesi için daha yüksek konsantrasyonlar, çok ilaca dirençli klinik izolatlar ve konvansiyonel antibiyotiklerle kombinasyon tedavilerini içeren ileri in vitro ve in vivo çalışmalara ihtiyaç vardır.
Anahtar Kelimeler: Antimikrobiyal direnç; kaempferol; fisetin; betulinik asit; broth mikrodilüsyon yöntemi.

INTRODUCTION

Antimicrobial resistance has become one of the most significant, kind of global public health issues, it really messes with how well infectious diseases can be treated. When antibiotics are used too long, or just not correctly, resistant bacterial strains show up faster, and the whole thing quietly weakens the effect of current therapeutic options [1]. so, finding new and actually effective antimicrobial agents has been getting more and more urgent. Lately, plant-derived natural bioactive compounds have pulled a lot of attention as potential alternative antimicrobial agents, mainly because they show a broad spectrum of biological activities, and they tend to have relatively low toxicity. Within clinically important opportunistic pathogens, *Pseudomonas aeruginosa* and *Staphylococcus aureus* are often named as major causes of both community acquired infections and healthcare associated infections. *P. aeruginosa* is a Gr (-), aerobic, motile, non-spore-forming opportunistic pathogen. It's spread pretty widely across nature, in soil, water, and on moist surfaces, and it can persist for long periods in hospital environments [2]. Because it needs very little in terms of nutrients, because it can form biofilms, and because it has a whole set of virulence factors, it is linked with serious infections, especially among immunocompromised patients [3]. This organism also appears in a broad range of clinical scenarios, such as respiratory tract infections, urinary tract infections, wound and burn infections, and bloodstream infections. It is also among the most frequently isolated nosocomial pathogens in intensive care units [4]. Besides its own intrinsic resistance mechanisms, *P. aeruginosa* also brings along a few acquired ones, like efflux pump overexpression , porin loss, β-lactamase production, and an enhanced biofilm formation, which together seriously restrict the usable treatment choices [5]. At the same time, the prevalence of resistance across multiple antibiotic classes , for instance carbapenems, keeps climbing. So there is now a clear, urgent push to find novel antimicrobial agents that can work against this pathogen. In that setting plant-derived, natural bioactive compounds have been showing up as very hopeful options for managing and treating *P. aeruginosa* infections. The reference strain *P. aeruginosa* ATCC 27853 is basically a well-studied clinical isolate from humans, with a well-defined antimicrobial susceptibility pattern. Because its susceptibility behavior stays reproducible, it gets used a lot as a quality control organism in antimicrobial susceptibility testing [6].
Staphylococcus species are everywhere in the environment, and they're also among the key parts of the normal human microbiota, sort of acting as important opportunistic pathogens [7]. These bacteria are

Gr +, non-motile, non-spore-forming, facultatively anaerobic, catalase-positive cocci , about 0.5–1.5 µm across. After 18–24 h of incubation on blood agar, they usually make smooth, convex, opaque colonies, with fairly clear borders, not really messy. Of all the Staphylococcus species, *S. aureus* is the most frequent reason for human infections, and it stands out from the other staphylococci because it shows a coagulase-positive phenotype [8]. The reference strain *S. aureus* ATCC 29213, which is commonly used in antimicrobial susceptibility testing, comes from a human clinical isolate and is known for being susceptible to methicillin and oxacillin [9].

S. aureus is behind a very broad range of diseases, going from mild-ish superficial skin and soft tissue infections, all the way to dangerous systemic infections. Besides toxin-linked conditions such as staphylococcal food poisoning, toxic shock syndrome, and staphylococcal scalded skin syndrome, it is also a major etiologic agent in osteomyelitis, septic arthritis, pneumonia, empyema, urinary tract infections, infective endocarditis, meningitis, and brain abscesses [10]. And meanwhile, the rising worldwide prevalence of methicillin-resistant *S. aureus*, MRSA, has made the search for new antimicrobial agents that actually work against this organism, even more urgent [11].

Among naturally occurring bioactive compounds, kaempferol fisetin, and betulinic acid have drawn quite a lot of scientific attention,mostly because they show a variety of pharmacological effects. Kaempferol and fisetin are plant-derived flavonoids, known for antioxidant, anti-inflammatory, and antimicrobial actions [12, 13]. Betulinic acid, which is a naturally occurring pentacyclic triterpenoid, has been described as having antimicrobial, antiviral, antioxidant, and antitumor properties [14]. Earlier investigations suggest that these agents could restrain microbial growth by using more than one route , for example damaging bacterial cell membrane integrity, reducing or disrupting biofilm formation, and interfering with essential cellular functions [12, 15, 16].

Even with this increasing attention toward these natural substances, comparative work that looks at their antimicrobial activities across different bacterial pathogens is still somewhat limited. In particular, trying to study the impact of kaempferol and fisetin on *P. aeruginosa* at the same time as the impact of kaempferol and betulinic acid on *S. aureus*, within the same experimental framework, may help in getting a fuller picture of their antimicrobial potential.

Therefore, the present study aimed to evaluate the in vitro antimicrobial activities of kaempferol and fisetin against *P. aeruginosa* and those of kaempferol and betulinic acid against *S. aureus* using the broth microdilution method.

MATERIALS AND METHODS

Reference strains of *P. aeruginosa* ATCC 27853 and *S. aureus* ATCC 29213 were used in this study. The natural compounds evaluated, namely kaempferol (BLDpharm, Cat No: BD33908), fisetin (Macklin, Cat No: F809597), and betulinic acid (BLDpharm, Cat No: BD1981) were supplied in powder form and dissolved in sterile dimethyl sulfoxide (DMSO). To minimize any potential antimicrobial effect of the solvent, the final concentration of DMSO in the test wells was maintained below 1% [17].

The antimicrobial activities of the natural compounds were evaluated using the broth microdilution method in sterile, flat-bottom 96-well microplates [18] according to the recommendations of the Clinical and Laboratory Standards Institute (CLSI) [31]. Two-fold serial dilutions of each compound were prepared in Mueller–Hinton Broth (MHB) over a concentration range of 1024–0.5 µg/mL for both *P. aeruginosa* and *S. aureus* . Bacterial inocula were adjusted to the 0.5 McFarland standard, and each well was inoculated to obtain a final bacterial density of approximately 5×10^5 CFU/mL. Positive control wells contained bacterial suspension and MHB, whereas negative control wells contained only MHB. In addition, compound control wells containing only the respective natural compound and MHB were included to account for possible interference of the intrinsic color of the compounds with optical density measurements.

For comparison, ciprofloxacin was used as the reference antibiotic for *P. aeruginosa*, whereas vancomycin was used for *S. aureus* . The antibiotics were prepared as two-fold serial dilutions in MHB at concentrations ranging from 32 to 0.25 µg/mL and were tested under identical experimental conditions [19, 20].

Microplates were incubated at 37°C for 24 h (Figure 1). Initially, the minimum inhibitory concentration (MIC) was intended to be determined by visual assessment of bacterial growth in the wells. However, the intense coloration of the natural compounds prevented reliable visual interpretation.

Therefore, bacterial growth was quantified spectrophotometrically by measuring the optical density at 600 nm (OD_{600}). To eliminate background interference caused by the compounds, OD_{600} values were corrected using the corresponding compound control wells.

To determine the minimum bactericidal concentration (MBC), aliquots from the microdilution wells were subcultured onto appropriate agar media and incubated at 37°C for 18–24 h (Figure 2). All experiments were performed independently in triplicate.

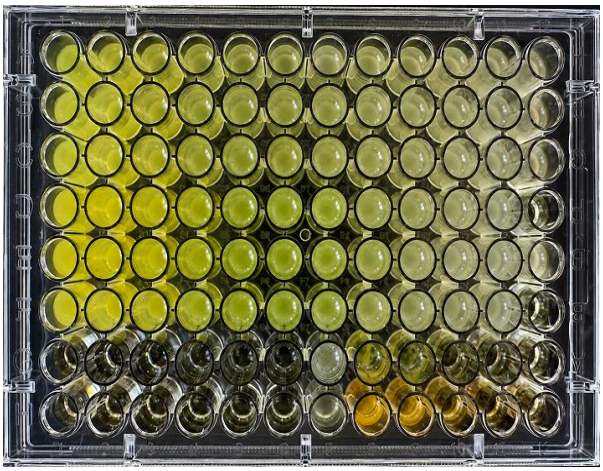


Figure 1 : Representative image of the 96-well microplate used for the broth microdilution assay after incubation at 37°C for 24 h.

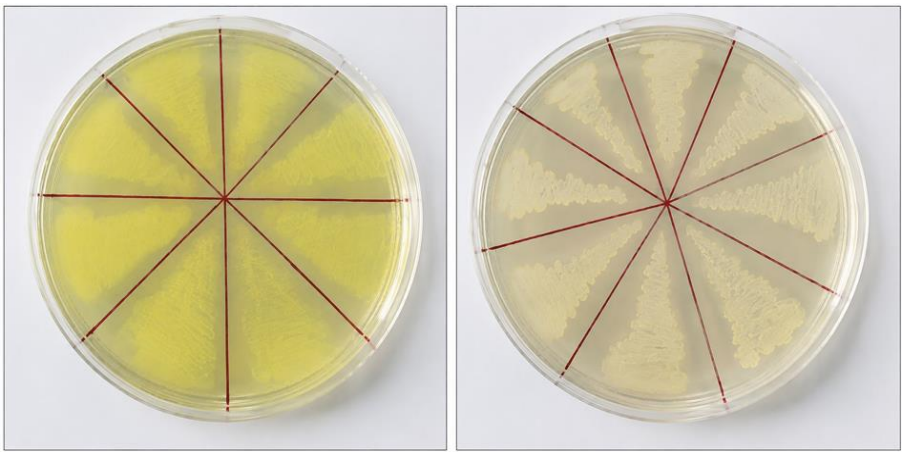
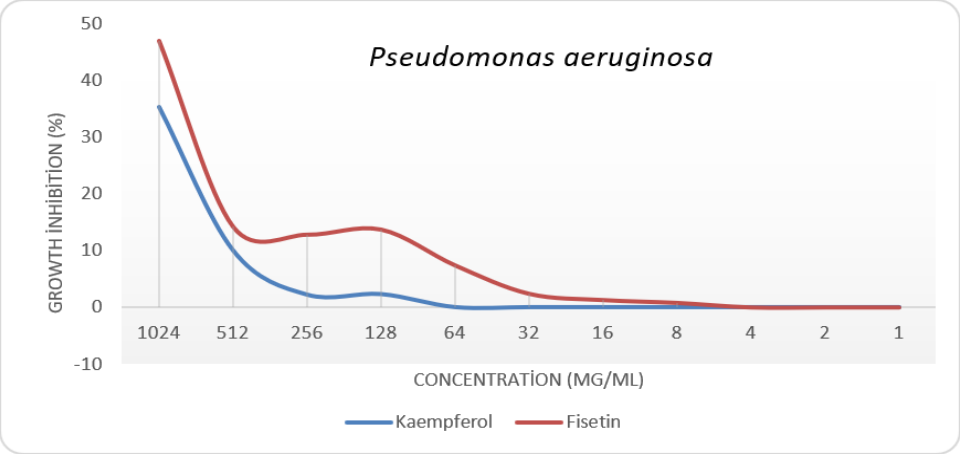


Figure 2 : Representative subculture plates showing bacterial growth from all tested concentrations after the broth microdilution assay for MBC determination.

RESULTS

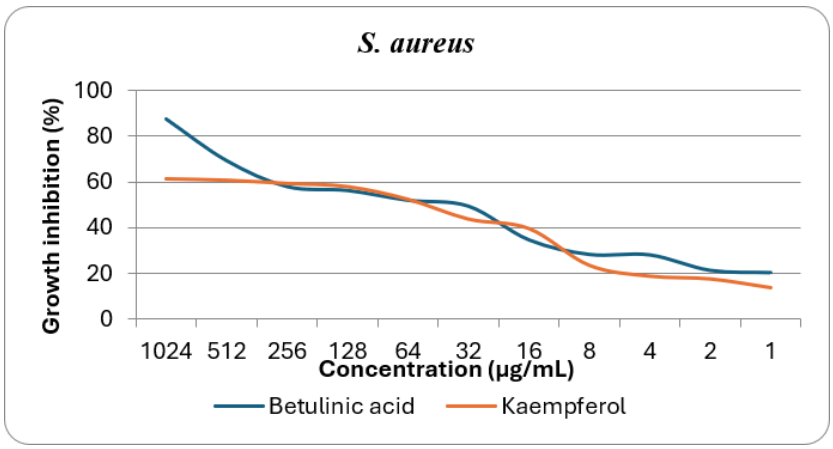
The MIC of the reference antibiotic ciprofloxacin against *P. aeruginosa* ATCC 27853 was 0.25 µg/mL, which seemed to fit inside the CLSI quality control range (0.25–1 µg/mL) for this reference strain. Likewise, the MIC of vancomycin against *S. aureus* ATCC 29213 came out as 0.5 µg/mL and was in line with the CLSI quality control criteria [21]. The consistency between the MICs that we observed for the reference antibiotics and the CLSI quality control ranges, kind of confirmed that the antimicrobial susceptibility testing was carried out using suitable experimental conditions and that the results could be trusted. Because the tested natural compounds have an inherent , noticeable color, a simple visual check for bacterial growth in the microdilution wells was not actually usable. So, the MIC could not be determined in the way CLSI recommends based on a visual endpoint.

Instead, bacterial growth was assessed spectrophotometrically by measuring optical density at 600 nm, OD600. For *P. aeruginosa* ATCC 27853, the OD600 readings showed that at the highest tested concentration (1024 µg/mL) kaempferol and fisetin reduced bacterial growth by roughly 35% and 46% respectively, compared to the positive control (Graph 1). Still, that inhibition effect dropped quite a lot as the concentrations got lower for both compounds, and full growth prevention was not reached within the tested interval. As a result, the MIC could not be calculated or reported. Also, when we did subculture of the samples taken from the microdilution assay, bacterial growth was seen at every concentration tested, and because of that the MBC could not be established.



Graph 1: Inhibitory effects of kaempferol and fisetin on *P. aeruginosa* growth based on OD_{600} measurements.

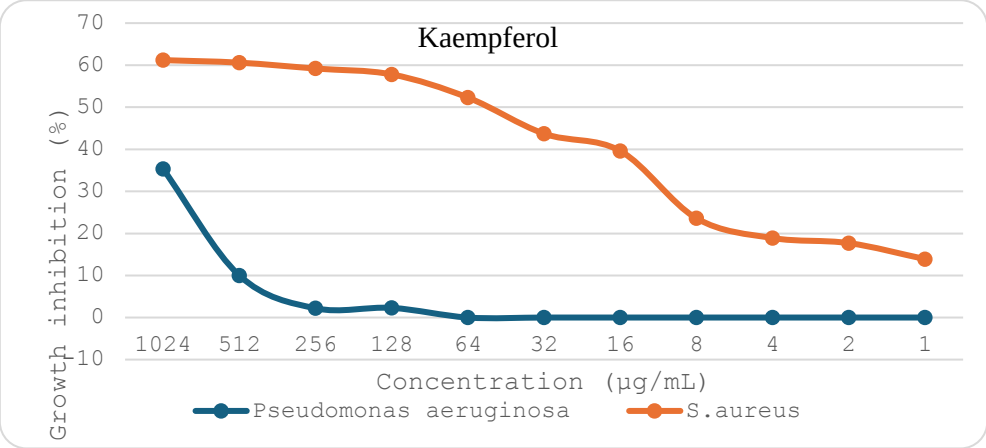
For *S. aureus* ATCC 29213, OD_{600} measurements revealed that kaempferol and betulinic acid inhibited bacterial growth by approximately 61% and 87%, respectively, at the highest tested concentration of 1024 µg/mL compared with the positive control (Graph 2). A concentration-dependent reduction in growth inhibition was observed for both compounds as the concentrations decreased. Since complete inhibition of bacterial growth was not achieved at any tested concentration, the MIC could not be determined. Likewise, bacterial growth was detected in all subcultures following the microdilution assay, preventing determination of the MBC.



Graph 2: Inhibitory effects of kaempferol and betulinic acid on *S. aureus* growth based on OD_{600} measurements.

Comparison of the antimicrobial activity of kaempferol against the two bacterial species demonstrated a greater inhibitory effect on *S. aureus* ATCC 29213 than on *P. aeruginosa* ATCC 27853. At the highest tested concentration (1024 µg/mL), kaempferol inhibited bacterial growth by approximately 61% in *S. aureus* and 35% in *P. aeruginosa* (**Graph** 3).

These findings indicate that, within the tested concentration range, kaempferol exhibited greater antibacterial activity against the Gr (+) organism than against the Gr (-) organism.



Graph 3: Inhibitory effects of kaempferol and betulinic acid on *P. aeruginosa* and *S. aureus* growth based on OD_{600} measurements.

DISCUSSION AND CONCLUSION

In the present study, the in vitro antimicrobial activities of kaempferol and fisetin against *P. aeruginosa* ATCC 27853, and those of kaempferol and betulinic acid against *S. aureus* ATCC 29213, were evaluated using the broth microdilution method. The MIC values obtained for the quality control antibiotics, ciprofloxacin and vancomycin, were within the quality control ranges recommended by the CLSI, confirming the validity of the experimental conditions and the reliability of the susceptibility testing procedure (CLSI, 2025). Although none of the tested natural compounds completely inhibited bacterial growth within the concentration range evaluated, precluding the determination of MIC and MBC values, spectrophotometric OD_{600} measurements demonstrated concentration-dependent inhibition of bacterial growth.

One of the major technical challenges associated with antimicrobial studies involving natural phenolic compounds is their poor aqueous solubility. Since kaempferol, fisetin, and betulinic acid are hydrophobic molecules, dimethyl sulfoxide (DMSO) was used as the solvent. To minimize any potential antimicrobial effect of the solvent itself, the final concentration of DMSO was maintained below 1% [17]. Nevertheless, limiting the DMSO concentration restricted the preparation of higher concentrations of the tested compounds, representing one of the principal limitations of this study. The inability to achieve complete bacterial growth inhibition even at the highest tested concentration (1024 µg/mL) suggests that evaluating higher concentrations may yield different outcomes.

Kaempferol and fisetin inhibited the growth of *P. aeruginosa* by approximately 35% and 47%, respectively. Although these findings indicate that both compounds exert concentration-dependent inhibitory effects, complete growth inhibition required for MIC determination according to CLSI criteria was not achieved. This observation is not unexpected, considering that *P. aeruginosa* is intrinsically resistant to numerous antimicrobial agents owing to its low outer membrane permeability, multiple efflux pump systems, biofilm-forming capacity, and other intrinsic resistance mechanisms [5]. Furthermore, the lipopolysaccharide-rich outer membrane of Gr (-) bacteria substantially restricts the intracellular penetration of hydrophobic flavonoids [22]. Accordingly, flavonoids have consistently been reported to exhibit lower antibacterial activity against Gr (-) bacteria than against Gr (+) organisms [23].

In the present study, no MIC value could be determined for kaempferol against *P. aeruginosa*. However, previous studies have reported MIC values ranging from 32 µg/mL to >1000 µg/mL for this organism [24, 25]. Such variability is likely attributable to differences in bacterial strains, inoculum density, experimental protocols, solvent systems, and susceptibility testing methodologies.

Likewise, fisetin has been reported to exhibit moderate antibacterial activity against *P. aeruginosa*, although its efficacy varies considerably depending on the experimental conditions [16, 26]. These findings are consistent with our observation of concentration-dependent bacterial growth inhibition without complete suppression of bacterial proliferation.

In contrast, more pronounced inhibitory activity was observed against *S. aureus* . Kaempferol and betulinic acid inhibited bacterial growth by approximately 61% and 88%, respectively. Nevertheless, complete inhibition was not achieved at any tested concentration, preventing determination of MIC and MBC values. The greater susceptibility of *S. aureus* may be attributed to the absence of an outer membrane in Gr (+) bacteria, allowing natural compounds to penetrate the cell wall more readily and interact more efficiently with the cytoplasmic membrane [27]. This structural difference may explain why kaempferol exhibited stronger inhibitory activity against *S. aureus* than against *P. aeruginosa*.

Previous studies have demonstrated that kaempferol primarily suppresses biofilm formation rather than exerting direct bactericidal activity against certain *S. aureus* strains, while showing only limited effects on planktonic bacterial growth [25, 28]. These observations are consistent with the partial growth inhibition observed in the present study. Similarly, betulinic acid has been reported to possess antibacterial activity against various Gr (+) bacteria through multiple mechanisms, including disruption of membrane integrity, interference with energy metabolism, induction of reactive oxygen species, and inhibition of biofilm formation [29, 30]. The substantial growth inhibition observed in our study is consistent with these proposed mechanisms. However, further investigations involving membrane permeability assays, gene expression analyses, and electron microscopy are required to elucidate the precise antibacterial mechanisms of these compounds.

Because the tested natural compounds exhibited intense intrinsic coloration, reliable visual assessment of MIC values according to CLSI recommendations was not feasible. Therefore, bacterial growth was quantified spectrophotometrically using OD_{600} measurements. Appropriate solvent and compound control wells were included to eliminate interference arising from the optical properties of the tested compounds. This approach provides a more reliable assessment of antimicrobial activity when evaluating naturally colored compounds.

Several limitations should be considered when interpreting the findings of this study. First, only reference ATCC strains were evaluated, whereas clinical isolates were not included. Second, the poor aqueous solubility of the tested compounds prevented evaluation at concentrations higher than 1024 µg/mL. Furthermore, only the antimicrobial activities of the compounds alone were investigated, and their potential synergistic or additive effects in combination with conventional antibiotics were not assessed. Future studies should focus on improving compound solubility using nanoparticle, liposome, or cyclodextrin-based delivery systems, evaluating higher concentrations, including multidrug-resistant clinical isolates, and investigating antibiotic combination therapies to better define the therapeutic potential of these natural compounds.

In conclusion, kaempferol, fisetin, and betulinic acid were unable to completely inhibit bacterial growth within the tested concentration range, and consequently MIC and MBC values could not be determined. Nevertheless, the marked growth inhibition observed with betulinic acid against *S. aureus* and fisetin against *P. aeruginosa* suggests that these natural compounds may serve as promising adjunctive antimicrobial agents rather than stand-alone bactericidal agents. Further in vitro and in vivo studies involving higher concentrations, resistant clinical isolates, and combination therapies with conventional antibiotics are warranted to fully elucidate their therapeutic potential.

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İNSAN ONURUNA YAKIŞIR İŞ İÇİN İNSAN KAYNAKLARI YÖNETİMİNİN ROLÜNE İLİŞKİN BİR İNCELEME

AN INVESTIGATION ON THE ROLE OF HUMAN RESOURCE MANAGEMENT FOR DECENT WORK WITH DIGNITY

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ÖZET
İnsan onuruna yakışır işin sağlanmasında örgütlerde İnsan Kaynakları (İK) biriminin rolü, kapsamı ve sınırları üzerine farklı görüşler bulunmaktadır. Birinci görüş, İK'nın tamamen örgütün kâr amacı doğrultusunda tarafsız bir konumda kalması gerektiğini savunurken; karşıt görüş, İK'nın insan onuruna yakışır bir iş ortamı sunma hususunda etik bir sorumluluk taşıdığını ve belirli ilkeler çerçevesinde hareket etmesi gerektiğini öne sürmektedir. Bu çalışma, ikinci görüşten hareketle örgütlerin çalışma yaşamına dair aktif ve etik bir sorumluluğa sahip olduğunu kabul etmektedir. Bu doğrultuda çalışma; İK'nın varoluşsal seçim, göreceli ahlaki özerklik, tartışma ve diyalog ile evrensel norm ve ilkelere bağlılık ilkeleri çerçevesinde hareket ederek sürdürülebilir bir çalışma düzenine katkı sağlayabileceğini savunmaktadır. Bu ilkelerden varoluşsal seçim, İK yöneticisinin insan onuruna yakışır bir yönetim adına kötülük yapmaktansa haksızlığa uğramayı yeğleyecek bir dürüstlük sergilemesini; göreceli ahlaki özerklik, yöneticinin somut örgüt veya toplum normlarını vicdanı ve soyut değerleri ışığında eleştirel bir süzgeçten geçirebilme yetisini kapsar. Tartışma ve diyalog, kararların mutlak bilgiye değil, dürüst bireyler arası müzakerelere dayanmasını ifade ederken; evrensel norm ve ilkelere bağlılık ise yöneticilerin karar süreçlerinde rehber edinebilecekleri ahlak, adalet ve bakım ilkelerini temsil etmektedir. Bu bağlamda çalışma iki aşamalı bir yöntem izlemektedir: İlk aşamada, insan onuruna yakışır iş ve İK uygulamalarını bahsi geçen ilkeler doğrultusunda doğrudan ele alan yayınlar eleştirel bir literatür taramasıyla derinlemesine incelenmektedir. İkinci aşamada ise İKY ve insan onuruna yakışır iş arasındaki ilişkiyi daha geniş bir perspektifle ele alan çalışmalar, Web of Science (WoS) veri tabanı kullanılarak bibliyometrik analiz ve kavramsal haritalama yöntemleriyle çözümlenmektedir. Böylece literatüre yapılan katkılar, tarihsel gelişim, araştırma eğilimleri ve öne çıkan temalar ortaya konularak akademisyenler ve uygulayıcılar için özgün öneriler sunulması amaçlanmaktadır.
Anahtar Kelimeler: İnsana yakışır iş, İKY, İK uygulamaları, sürdürülebilirlik, Etik İK.

ABSTRACT
There are varying perspectives regarding the scope and boundaries of the role of Human Resources (HR) departments in organizations with respect to decent work with dignity. While one line of thought argues that HR should remain neutral, strictly aligned with the organization's profit motives, an opposing view posits that HR bears a significant responsibility for ensuring decent work and must act in accordance with specific ethical principles and values. Grounded in the latter perspective, this study assumes that organizations hold an active and ethical responsibility toward work life. Accordingly, it argues that HR can contribute to a sustainable work environment by acting within the framework of fundamental principles, namely existential choice, relative moral autonomy, debate and dialogue, and commitment to universal norms and principles. Among these principles, existential choice implies an existential integrity wherein HR managers prefer suffering injustice over committing it to uphold human dignity. Relative moral autonomy refers to a manager's capacity to critically evaluate concrete organizational or societal norms through their conscience and abstract values rather than adhering to them blindly. Debate and dialogue signify that decision-making should rely on authentic deliberation among honest individuals rather than absolute assumptions, whereas commitment to universal norms and principles represents guiding frameworks-comprising ethics, justice, and care-that managers can utilize during decision-making processes. In this context, the study adopts a two-stage approach: First, it conducts a critical literature review to thoroughly examine studies directly addressing decent work and HR practices within the framework of these principles.

Second, it analyzes broader literature exploring the relationship between HRM and decent work through bibliometric analysis and conceptual mapping using the Web of Science (WoS) database. Ultimately, the study aims to reveal historical trends, research orientations, and major contributions to the field, offering valuable theoretical and practical recommendations for researchers and practitioners.
Keywords: Decent work, HRM, HR practice, Sustainability, Ethical HR.

ARTIFICIAL INTELLIGENCE IN ORAL AND MAXILLOFACIAL RADIOLOGY: CURRENT APPLICATIONS, CLINICAL IMPACT, AND FUTURE PERSPECTIVES

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ABSTRACT
Artificial intelligence (AI) is transforming oral and maxillofacial radiology by enabling a shift from subjective, manual radiographic assessment to highly objective, data-driven diagnostic frameworks. This research aimed to evaluate the clinical impact of AI subfields such as Machine Learning (ML) and Deep Learning (DL), with a specific focus on the performance of Convolutional Neural Networks (CNNs) in processing 2D and 3D dental imaging. Evidence indicates that AI models can perform high-speed segmentation and detection tasks with accuracy levels that often replicate or exceed those of experienced dental specialists. The main reported applications include detecting dental caries, evaluating periodontal bone loss, identifying periapical pathologies, and automating the localisation of cephalometric landmarks. Furthermore, AI is increasingly utilised in specialised areas such as implant planning, vertical root fracture detection, and forensic odontology for age and gender determination. Besides clinical diagnosis, the advent of large language models (LLMs) and chatbots has opened up opportunities for patient education and clinical decision support. Despite these technical advances, the use of AI in routine clinical workflows continues to face important challenges, including data privacy concerns; the need for large and diverse high-quality datasets; the potential for algorithmic bias; and the essential requirement for ethical frameworks to ensure patient safety. Ultimately, the existing literature indicates that AI will not replace the dental professional, but will act as an essential supportive tool that will increase diagnostic accuracy, decrease clinician workload, and improve overall patient outcomes.
Keywords: Artificial Intelligence, Deep Learning, Machine Learning, Dentistry, Dental Imaging

INTRODUCTION
Regarded as one of the most revolutionary contributions of the "Fourth Industrial Revolution" to healthcare, artificial intelligence represents the capability of machines to replicate cognitive processes traditionally considered exclusive to human intelligence, such as learning, analysing complex problems, and clinical decision-making (Alahmari et al., 2025; Helvacioglu-Yigit et al., 2025). Traditional workflows in dental radiology rely heavily on clinician visual perception and subjective interpretation (Alahmari et al., 2025). These conventional methods are susceptible to clinician physiological fatigue, variations in professional experience levels, and inter-observer variability among different experts evaluating the same image (Alahmari et al., 2025).

The dramatic increase in computing power and the rise of "big data" have transformed these manual evaluation procedures into automated, objective, data-driven systems (Alahmari et al., 2025; Ozkesici & Yilmaz, 2021). While the human eye may struggle to detect subtle density variations and microscopic pathological details within each pixel of a radiological image, AI systems can analyse far more radiographic data in minutes than a clinician might review over an entire professional career (Ozkesici & Yilmaz, 2021). This advanced technology standardises the diagnostic process by detecting pathological deviations at the pixel level and aims to minimise errors attributable to human oversight (Ozkesici & Yilmaz, 2021). The integration of AI into dental practice represents a technological shift that not only accelerates diagnostic speed but also establishes an objective, data-driven standard for treatment planning for every patient (Alahmari et al., 2025; Ozkesici & Yilmaz, 2021).

Current evidence demonstrates that AI models achieve rapid segmentation with accuracy rates that match or exceed those of experienced experts in tasks such as caries detection, periodontal bone loss analysis, and cephalometric landmark identification (Akdogan & Ozdemir, 2023; Bilgir et al., 2021).

Despite data privacy and ethical challenges, AI is positioned not as a competitor to the dentist, but as an indispensable decision-support tool that enhances diagnostic accuracy and operational efficiency (Akdogan & Ozdemir, 2023).
This research aimed to explore the clinical impact of AI subfields, such as Machine Learning (ML) and Deep Learning (DL), with particular focus on the performance of Convolutional Neural Networks (CNNs) in 2D and 3D dental imaging.

MATERIALS AND METHODS

This study is a comprehensive literature review evaluating AI applications and technological shifts in oral and maxillofacial radiology. Academic evidence was synthesised by searching international databases, including PubMed and Google Scholar, using keywords such as "Artificial Intelligence," "Deep Learning," "Oral and Maxillofacial Radiology," and "Neural Networks". Diagnostic accuracy rates, technological architectures (e.g., CNNs, SAMs), and ethical frameworks reported in the recent literature were systematically analysed.

RESULTS AND DISCUSSIONS

Technological Framework: Machine Learning and Deep Learning

At the core of AI applications lies Machine Learning (ML), which learns patterns directly from data without being explicitly programmed (Helvacioglu-Yigit et al., 2025). Deep Learning (DL), a subfield of ML, utilises multi-layered artificial neural networks to process complex data patterns (Helvacioglu-Yigit et al., 2025). Specifically, Convolutional Neural Networks (CNNs) are the dominant architecture for analysing visual information, such as radiographs and Cone Beam Computed Tomography (CBCT) (Helvacioglu-Yigit et al., 2025).
Furthermore, the emerging Segment Anything Model (SAM) architecture in segmentation can generalise across diverse tasks, unlike traditional models trained for single specific functions (Alahmari et al., 2025).
SAM models reduce the manual annotation burden on clinicians, thereby enhancing autonomy and workflow speed (Alahmari et al., 2025). In decision-support processes, Large Language Models (LLMs) such as ChatGPT are utilised to simplify radiology reports for patient education and to offer clinical decision support (Helvacioglu-Yigit et al., 2025).

Clinical Applications and Performance Analysis

In dentistry, the most commonly used artificial intelligence technologies include deep learning, neural networks, and machine learning. Neural networks, in particular, are widely used in image analysis and diagnosis, yielding effective results in the automated interpretation of dental radiographs, CT scans, and other images. Deep learning and convolutional neural networks also stand out for their contributions to image segmentation, diagnosis, and treatment planning. Furthermore, robotic systems and CAD/CAM technologies utilise artificial intelligence algorithms in dental restoration and prosthesis design. In orthodontics, the most common artificial intelligence applications are treatment planning, growth and development assessment, and prediction of tooth movement and prognoses. In particular, AI models achieve high accuracy in determining the need for extraction before treatment and in cephalometric radiographic analysis. Additionally, deep learning algorithms have been developed for automated detection of cephalometric landmarks and risk analysis of treatment outcomes, achieving accuracy rates of 80-99% (Shan et al., 2021). In growth and development assessment, artificial intelligence systems capable of automatically ageing bone and predicting neck growth are available. These are the most preferred applications in orthodontic practice to accelerate clinical decision-making and increase accuracy. In oral, dental, and maxillofacial surgery, the most commonly used artificial intelligence applications are in implantology and surgical planning. In particular, convolutional neural networks are used to determine dental implant brands and treatment stages, thereby facilitating processes such as implant placement and bone quality assessment. In addition, artificial intelligence algorithms exist for the automated assessment of osseointegration quality and bone loss around implants. In surgical procedures, robotic techniques are used to mill facial and bone structures, perform osteotomy incisions, and plan osteosynthesis plates (Aminoshariae et al., 2021).

For example, robotic systems are used in cleft palate repair to reduce the risk of nerve damage and minimise the need for a second surgical operation. These applications are the most preferred artificial intelligence-based solutions to increase surgical success rates and reduce complications. The most commonly used artificial intelligence (AI) applications in periodontology are used for diagnosis, classification, and staging of periodontal diseases. In particular, convolutional neural networks (CNNs) are used to assess radiographic bone loss and automatically determine the stages of periodontal disease. These systems can classify the different stages of periodontitis with high accuracy by detecting the periodontal bone and enamel-cementum junction levels on panoramic radiographs (Aminoshariae et al., 2021). Furthermore, to improve oral hygiene, robotic systems and AI-based toothbrushing robots have been developed to replace or support manual brushing. These applications yield effective results in early disease diagnosis and treatment and are the most preferred AI solutions in periodontology. In endodontics, the most commonly used AI applications focus on evaluating root canal anatomy, detecting periapical lesions and root fractures, and reducing diagnostic errors. In particular, neural networks (AI) are successfully used to diagnose periodontal bone loss and grade diseases such as periodontitis in panoramas and other radiographs (Aminoshariae et al., 2021). Furthermore, deep learning systems have been developed to automate the detection of root canals and periapical lesions, thereby improving dentists' diagnostic accuracy. For example, AI-assisted image analysis applications are widely used for classifying root morphology and detecting fractures. These reduce diagnostic errors and improve the precision of treatment planning.

The most commonly used artificial intelligence applications in prosthetic dentistry include automated design of tooth preparations, colour matching, and planning of prosthetic restorations. AI models, especially those focused on tooth anatomy and colour matching, enable the prediction of optimal parameters for metal substructure casting, porcelain selection, and successful colour matching. Furthermore, digital smile design and automated image integration systems that can be integrated with the face play a significant role in meeting aesthetic expectations. The accuracy and precision of tooth preparation have been increased with robotic systems and occult preparation technologies. These applications reduce clinical time and improve aesthetic and functional outcomes (Nguyen et al., 2021).

In radiology, the most commonly used artificial intelligence applications are heavily utilised for automated image interpretation, pathology detection, and measurement. In particular, convolutional neural networks (CNNs) are used to automate the diagnosis of diseases such as caries, periodontal bone loss, tooth root morphology, bone quality, and periimplantitis in dental and maxillofacial radiographs (Shan et al., 2021). Artificial intelligence algorithms are also used to diagnose maxillary sinus pathologies and automatically differentiate lesions such as dental granulomas and radicular cysts on cone-beam computed tomography. AI techniques also facilitate image analysis and improve accuracy in areas of superimposition and low contrast in radiological images. These are the most preferred applications in dental radiology to increase diagnostic speed and improve clinical accuracy. AI has been used to detect proximal caries and periapical pathologies that are sometimes undetectable on radiographic images due to superimposition and low contrast (Geetha et al., 2020). Furthermore, good results have been obtained in classifying and detecting dental caries using a convolutional neural network trained on periapical radiographs (Flores et al., 2009; Okada et al., 2015). In addition, artificial intelligence algorithms have been used in radiology to detect periodontal bone loss. Another application of artificial intelligence in radiology is the diagnosis of maxillary sinus pathologies. It has been reported that artificial intelligence algorithms can support dentists in diagnosing maxillary sinusitis (Kim et al., 2019). Additionally, Flores et al. (2009) and Okada et al. (2015) developed computer-aided diagnosis systems to automatically distinguish dental granuloma and radicular cysts in cone-beam computed tomography using convolutional neural networks.

In tooth detection and numbering, CNN-based models can number teeth on panoramic radiographs with up to 99% accuracy and detect impacted teeth with 100% precision (Table 1; Bilgir et al., 2021). In caries and periodontal analysis, AI models achieve accuracy rates of 80-89% in detecting interproximal caries, matching or exceeding the detection rates of expert dentists (Table 2; Koca Unsal & Orhan, 2022; Tosun et al., 2026).

In endodontics and maxillofacial pathology, DL algorithms demonstrate 93% accuracy in identifying periapical pathologies on CBCT scans (Bilgir et al., 2021).

Additionally, artificial neural networks achieve a 96% success rate in measuring root canal working length (Koca Unsal & Orhan, 2022). In surgical, orthodontic, and forensic applications, cephalometric landmarks can be automatically identified by AI in as few as 90 seconds (Bilgir et al., 2021).

Table 1. Summary of AI model performance in oral radiology (Bilgir et al., 2021; Tosun et al., 2026)

Application Area	**Architecture Used**	**Accuracy / Success Rate (%)**
Tooth Numbering	CNN-Based	99
Periapical Pathology	U-Net / Diagnocat	93
Root Canal Length	Artificial Neural Networks	96
Osteoporosis Screening	DCNN / ResNet	98.5
Caries Detection	YOLO V4 /CNN	80-89

Table 2. Lesion classification success of different CNN architectures (Tosun et al., 2026)

Model	**Lesion Detection Accuracy (%)**
GoogleNet	95.6
AlexNet	93.4
VGG16	64.7

DISCUSSION, CHALLENGES, AND FUTURE PERSPECTIVES

AI applications in the field of dental radiology are used for (i) diagnosis, (ii) image processing/reconstruction, (iii) forensic medicine, (iv) patient/student training, (v) quality control, and (vi) automated reporting purposes (Pauwels R., 2021; Cesur Aydın, 2025).

Although the integration of AI into clinical settings provides substantial advantages, the major barrier to routine deployment remains the opacity of decision-making algorithms, commonly referred to as the "black-box" issue (Tosun et al., 2026). While LLMs and chatbots assist in report simplification, the risk of false information (hallucination) necessitates that a professional clinician verify all generated outputs to safeguard patient care (Helvacioglu-Yigit et al., 2025).

From a medico-legal standpoint, because current legal frameworks classify AI as a "decision support system," primary legal responsibility for misdiagnosis or incorrect treatment planning rests with the attending clinician who validates the system's output and makes the final decision (Akdogan & Ozdemir, 2023; Tosun et al., 2026).

CONCLUSION

Artificial intelligence is transforming oral and maxillofacial radiology from manual and subjective processes into an objective, data-driven framework, serving as an indispensable decision-support system that enhances clinical competence (Akdogan & Ozdemir, 2023; Alahmari et al., 2025).

To increase the use of artificial intelligence in dentistry, multidisciplinary collaborations should be encouraged, with experts from medical, technological, and ethical fields working together. This helps to address clinical knowledge gaps and prevent misinterpretations during algorithm development. Furthermore, the creation and sharing of high-quality, large datasets should be ensured to improve the training and accuracy of artificial intelligence. Legal regulations and standards should also be established to ensure that artificial intelligence is used ethically and with respect for patient privacy in clinical practice. Increasing education and awareness is also crucial, and continuous training programs should be developed to enable dentists to use artificial intelligence effectively and safely.

Finally, collaborations between the government and the private sector can be established to strengthen technological infrastructure and reduce costs, thus enabling more clinics and research institutions to adopt artificial intelligence. These measures can pave the way for the effective and ethical use of artificial intelligence in dentistry.

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TÜRKİYE'DE MAGNEZYUM, D VİTAMİNİ, OMEGA-3 VE ÇİNKO BESİN TAKVİYELERİNE YÖNELİK DİJİTAL İLGİNİN GOOGLE TRENDS VERİLERİYLE İNCELENMESİ

AN ANALYSIS OF DIGITAL INTEREST IN MAGNESIUM, VITAMIN D, OMEGA-3 AND ZINC DIETARY SUPPLEMENTS IN TURKEY THROUGH GOOGLE TRENDS DATA

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ÖZET

Amaç: Bu çalışmada, Türkiye'de magnezyum, D vitamini, omega-3 ve çinko besin takviyelerine yönelik toplumun internet arama davranışının Google Trends verileri kullanılarak incelenmesi amaçlanmıştır. Çalışma, bu ilginin zaman içindeki değişimini, mevsime göre farklılığını ve bölgeler arasındaki farkını ortaya koymayı; bulguları sağlık yönetimi ve halk sağlığı iletişimi açısından değerlendirmeyi hedeflemektedir.

Gereç ve Yöntem: Google Trends üzerinden, Türkiye geneli için son beş yıla (2021-2026) ait haftalık arama verileri (N=261) toplanmıştır. Ayrıca Google Trends'in 81 il için sunduğu bölgesel veriler değerlendirilmiştir. Değişkenlerin normal dağılıma uygunluğu sınanmış; sonuçlar, çalışmada parametrik olmayan istatistiksel yöntemlerin (Mann-Kendall trend testi, Kruskal-Wallis testi, Spearman korelasyonu) kullanılmasını desteklemiştir. Bulguların güvenilirliğini artırmak amacıyla temel analizler Python, IBM SPSS Statistics ve Microsoft Excel olmak üzere üç farklı istatistik yazılımında bağımsız olarak tekrarlanmış ve tutarlı sonuçlara ulaşılmıştır.

Bulgular

Magnezyum aramalarında son beş yılda istatistiksel olarak anlamlı, sürekli bir artış gözlenmiş (Mann-Kendall τ=0,689; $p<0,001$), ilgi yaklaşık iki buçuk katına çıkmıştır. D vitamini aramaları düzenli olarak kış aylarında artıp yaz aylarında azalmakta; bu örüntü, güneş ışığıyla bağlantısı bilinen bir bulguyla uyumludur. Çinko aramalarında ise beklenenin aksine kışın değil, sonbaharda (Eylül ayında) istatistiksel olarak anlamlı bir yükselme görülmüştür. Omega-3'e yönelik ilgi diğer üç takviyeye kıyasla çok daha düşük kalmış (ortalama puan 100 üzerinden 1,5), ancak son dönemde anlamlı bir artış eğilimine girmiştir (τ=0,297; $p<0,001$). Takviyeler arası ilişkiler incelendiğinde, D vitamini ile çinko arasında orta düzeyde, istatistiksel olarak anlamlı bir pozitif ilişki bulunmuş (r=0,574; $p<0,001$); diğer ikili karşılaştırmalarda ilişkiler zayıf veya anlamsız kalmıştır. Coğrafi bölgeye göre karşılaştırıldığında, Batı illerinde (Ege ve Marmara) magnezyum ilgisinin payı yaklaşık %49 iken, doğu illerinde (Doğu Anadolu) bu pay %40'a inip D vitamini ilgisinin payı %39'a yükselmektedir.

Sonuç

Bulgular, besin takviyelerine yönelik toplumsal ilginin türe ve bölgeye göre istatistiksel olarak anlamlı biçimde farklılaştığını göstermektedir. Analizlerin üç farklı istatistik yazılımında bağımsız olarak tekrarlanması, bulguların güvenilirliğini desteklemektedir. Özellikle magnezyuma yönelik hızlı artışın, anketlerde henüz yakalanmamış yeni bir eğilime işaret edebileceği düşünülmektedir. Bulgular, halk sağlığı kurumlarının bilgilendirme çalışmalarını zamanlama ve hedefleme açısından yönlendirebilir.

Anahtar Kelimeler: Google Trends, besin takviyesi, dijital sağlık davranışı

ABSTRACT

Purpose

This study aims to examine the internet search behavior of the Turkish population toward magnesium, vitamin D, omega-3, and zinc dietary supplements using Google Trends data. The study seeks to reveal the change in this interest over time, its seasonal variation, and the differences between regions, and to evaluate the findings from the perspective of health management and public health communication.

Materials and Methods

Weekly search data (N=261) covering Turkey as a whole for the last five years (2021-2026) were collected from Google Trends. In addition, the regional data provided by Google Trends for 81 provinces were evaluated. The variables were tested for normal distribution; the results supported the use of non-parametric statistical methods (Mann-Kendall trend test, Kruskal-Wallis test, Spearman correlation) in the study. To increase the reliability of the findings, the main analyses were independently repeated in three different statistical software programs — Python, IBM SPSS Statistics, and Microsoft Excel — and consistent results were obtained.

Results

A statistically significant, continuous increase was observed in magnesium searches over the last five years (Mann-Kendall τ=0.689; $p<0.001$), with interest rising to approximately two and a half times its initial level. Vitamin D searches regularly increase in winter months and decrease in summer months, a pattern consistent with the well-known association with sunlight exposure. For zinc searches, contrary to expectations, a statistically significant rise was observed not in winter but in autumn (September). Interest in omega-3 remained much lower than the other three supplements (mean score of 1.5 out of 100), but has recently entered a significant upward trend (τ=0.297; $p<0.001$). When the relationships between supplements were examined, a moderate, statistically significant positive relationship was found between vitamin D and zinc (r=0.574; $p<0.001$); relationships in the other pairwise comparisons remained weak or non-significant. When compared by geographic region, the share of magnesium interest was approximately 49% in western provinces (Aegean and Marmara), whereas in eastern provinces (Eastern Anatolia) this share fell to 40% while the share of vitamin D interest rose to 39%.

Conclusion

The findings show that societal interest in dietary supplements differs statistically significantly by type and by region. The independent repetition of the analyses across three different statistical software programs supports the reliability of the findings. In particular, the rapid rise in interest toward magnesium is thought to potentially point to a new trend not yet captured by surveys. The findings may help guide the timing and targeting of public health institutions' information efforts.

Keywords: Google Trends, dietary supplements, digital health behavio

İŞLETMELERİN WEB SİTESİ SAHİPLİĞİ DIŞ TİCARETİ ETKİLER Mİ? OECD ÜLKELERİ İÇİN BULGULAR

DOES BUSINESS WEBSITE OWNERSHIP MATTER FOR FOREIGN TRADE? EVIDENCE FROM OECD COUNTRIES

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ÖZET

Bilgi ve iletişim teknolojilerinde yaşanan hızlı gelişmeler, geleneksel ticaret yöntemlerinin dijital ortama taşınmasını sağlayarak elektronik ticaretin küresel ölçekte yaygınlaşmasına önemli katkıda bulunmuştur. İnternet erişiminin artması, dijital altyapının güçlenmesi ve bilgisayar kullanımının yaygınlaşması sayesinde işletmeler, geniş ürün yelpazelerini daha düşük maliyetlerle ulusal ve uluslararası pazarlara sunabilmekte, tüketiciler ise zaman ve mekân kısıtı olmaksızın ürün ve hizmetlere kolayca ulaşabilmektedir. Elektronik ticaret, işlem maliyetlerini azaltması, bilgiye erişimi kolaylaştırması ve pazar sınırlarını ortadan kaldırması nedeniyle uluslararası ticaretin gelişiminde önemli bir araç haline gelmiştir. Özellikle COVID-19 pandemisi sürecinde fiziksel ticaretin kısıtlanması, çevrim içi alışverişe olan talebi artırmış ve işletmelerin dijital dönüşüm süreçlerini hızlandırarak elektronik ticaretin uluslararası ticaretteki önemini daha da belirgin hale getirmiştir.

Bu çalışmanın amacı, bilgi ve iletişim teknolojilerindeki gelişmelerin uluslararası ticaret üzerindeki etkisini OECD ülkeleri örneğinde incelemektir. Bu kapsamda, 2005–2020 dönemine ait veriler kullanılarak 10 OECD ülkesinde (Avusturya, Estonya, Almanya, Yunanistan, Japonya, Kore, Norveç, Polonya, Slovakya ve Slovenya) şirketlerin web sitesi sahiplik oranları ile toplam ihracat ve ithalat değerleri arasındaki ilişki panel veri analizi çerçevesinde panel nedensellik yöntemiyle araştırılmıştır. Elde edilen bulgular, şirketlerin web sitesi sahiplik oranından hem ihracata hem de ithalata doğru tek yönlü bir nedensellik ilişkisinin bulunduğunu göstermektedir. Sonuçlar, işletmelerin dijital varlıklarının güçlendirilmesinin ve bilgi teknolojilerine yapılan yatırımların uluslararası ticaret performansını artırabileceğini ortaya koymaktadır. Bu bağlamda, dijital dönüşümü destekleyen politikaların geliştirilmesi ve işletmelerin elektronik ticaret altyapılarının güçlendirilmesi, ülkelerin dış ticaret performansının artırılmasına katkı sağlayabilecek önemli politika araçları olarak değerlendirilmektedir.

Anahtar Kelimeler: : E-ticaret, Web sitesi Sahipliği, Dış Ticaret, Dumitrescu–Hurlin Panel Nedensellik

ABSTRACT

Rapid advances in information and communication technologies have facilitated the digitalization of traditional trading practices, thereby making a significant contribution to the global expansion of e-commerce. The increasing availability of internet access, improvements in digital infrastructure, and the widespread use of computers have enabled businesses to offer a wide range of products to both domestic and international markets at lower costs. At the same time, consumers can conveniently access products and services regardless of time and location constraints. By reducing transaction costs, facilitating access to information, and eliminating geographical barriers, e-commerce has become an essential driver of international trade. Moreover, the COVID-19 pandemic further highlighted the importance of online shopping by accelerating digital transformation processes and increasing consumer demand for e-commerce as physical trade activities became restricted.

The primary objective of this study is to examine the impact of developments in information and communication technologies on international trade, with a particular focus on OECD countries.

To this end, panel causality analysis was employed to investigate the relationship between the proportion of enterprises with a website and the total values of exports and imports in ten OECD countries (Austria, Estonia, Germany, Greece, Japan, Korea, Norway, Poland, the Slovakia, and Slovenia) over the period 2005–2020. The empirical findings reveal a unidirectional causal relationship running from the proportion of enterprises with a website to both exports and imports. These results suggest that strengthening firms' digital presence and increasing investments in information technologies can enhance international trade performance. Accordingly, policies that promote digital transformation and support the development of e-commerce infrastructure are likely to play a significant role in improving countries' foreign trade performance and international competitiveness.

Keywords: E-commerce, Business Website Ownership, Foreign Trade, Dumitrescu–Hurlin Panel Causality Test

DENTAL AND ORAL MANIFESTATIONS OF CELIAC DISEASE: CLINICAL PATTERNS AND DIAGNOSTIC SIGNIFICANCE

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ABSTRACT
Celiac disease (CD) is a chronic systemic autoimmune disorder induced by gluten intake in genetically susceptible individuals and has an estimated prevalence of about 1% in the world population. Though it is primarily recognised for gastrointestinal symptoms, CD has a range of extraintestinal manifestations, and the oral cavity is often a “window” for early diagnosis. This research investigates the significant association between CD and different dental pathologies in children and adults. Dental enamel defects (DEDs) are the most common dental findings in CD patients, with a prevalence of 50% to 94.1%. These defects, usually symmetrical and chronological, are characterised by pitting, grooving, or permanent discolouration. Recent studies have also shown a significant association between CD and molar incisor hypomineralization (MIH), with children with CD having approximately 8.9 times the odds of MIH compared with healthy controls. Other common oral findings include delayed dental eruption (DDE) and maturation (DDM), recurrent aphthous stomatitis (RAS), atrophic glossitis, and xerostomia. These manifestations have a multifactorial pathogenesis, involving malabsorption of essential micronutrients during tooth development, particularly calcium and vitamin D, and autoimmune reactions in which antibodies to gliadin cross-react with enamel proteins, such as amelogenin. Importantly, dental lesions often occur in patients without gastrointestinal complaints, making dentists important “sentinels” in the detection of undiagnosed CD. While soft tissue lesions may improve with a strict gluten-free diet, once enamel damage is established, it is irreversible. Therefore, interdisciplinary collaboration between dental and medical professionals is essential for early screening and for improving patients' holistic health-related quality of life.
Keywords: Celiac disease, dental enamel defects, molar incisor hypomineralization, early diagnosis, oral manifestations.

INTRODUCTION
Celiac disease (CD) is a chronic, systemic, immune-mediated enteropathy triggered by dietary gluten and related prolamin proteins in genetically susceptible individuals who carry the HLA-DQ2 or HLA-DQ8 haplotypes (Rubio-Tapia et al., 2023; Abbasi et al., 2024). Gluten refers to a complex mixture of storage proteins found in widely consumed cereals, specifically wheat (gliadins and glutenins), barley (hordeins), and rye (secalins) (Abbasi et al., 2024; Doyle et al., 2025). Globally, the disease affects approximately 0.7% to 1.5% of the general population, with a noted upward trend in both prevalence and incidence in recent decades (Lebwohl and Rubio-Tapia, 2021; Gül et al., 2024; Doyle et al., 2025). CD is characterised by an aberrant immune response that leads to small-intestinal mucosal damage, including villous atrophy, crypt hyperplasia, and increased intraepithelial lymphocytes (Lucchese et al., 2023; Wieser et al., 2023; Abbasi et al., 2024). Historically regarded as a pediatric gastrointestinal illness defined by classical malabsorption symptoms such as chronic diarrhoea and weight loss, the clinical understanding of CD has evolved significantly (Adams et al., 2024; Doyle et al., 2025). Modern clinical patterns reveal a highly heterogeneous disorder in which many patients present with “non-classical” or extraintestinal manifestations that can involve the skin, bones, reproductive system, and oral cavity (Bektaş, 2024; Wieser et al., 2024; Doyle et al., 2025).
The oral cavity often serves as a primary site for extraintestinal manifestations of CD, and in many cases these manifestations may be the only presenting features of the disease (Macho et al., 2017; Wieser et al., 2023).

The most frequently documented oral findings include dental enamel defects (DEDs), recurrent aphthous stomatitis (RAS), delayed dental eruption (DDE), and molar incisor hypomineralization (MIH) (Macho et al., 2017; Alsadat et al., 2021; Bektaş, 2024).

Recent investigations have highlighted MIH as a distinct and clinically relevant phenotype within the spectrum of CD-related enamel disturbances (Tok et al., 2025; Wieser et al., 2023). Studies indicate that children with CD are significantly more likely to exhibit MIH than healthy controls, with research reporting that CD increases the likelihood of MIH occurrence by approximately 8.97 times (Tok et al., 2025). The etiopathogenesis of these dental manifestations is multifaceted, involving both the malabsorption of essential micronutrients—specifically calcium and vitamin D—and autoimmune reactions (Bektaş, 2024; Wieser et al., 2023; Tok et al., 2025). Evidence suggests that gluten-induced antibodies, such as anti-gliadin IgG, may cross-react with enamel matrix proteins like amelogenin and ameloblastin, thereby disrupting normal odontogenesis (Lucchese et al., 2023; Wieser et al., 2023; Bektaş, 2024).

The diagnostic significance of these oral patterns is paramount for early intervention (Wieser et al., 2023; Inchingolo et al., 2024). Because dental enamel development occurs during early childhood, the presence of these permanent, irreversible defects can provide a retrospective clinical record of early-life gluten sensitivity (Wieser et al., 2024; Tok et al., 2025). Furthermore, because oral lesions frequently precede gastrointestinal symptoms, dentists and pediatric dental specialists can play a pivotal role as "sentinels" in the early detection of unrecognised CD (Paul et al., 2016; Wieser et al., 2023; Inchingolo et al., 2024). Identifying these specific clinical patterns allows for early referral to gastroenterologists, facilitating prompt diagnosis and the initiation of a strict lifelong gluten-free diet (GFD) (Inchingolo et al., 2024; Rubio-Tapia et al., 2023; Gül et al., 2024). While a GFD can resolve soft-tissue lesions such as RAS, it cannot reverse established DEDs or MIH, further emphasising the need for early diagnostic intervention to prevent permanent dental complications (Bektaş, 2024; Wieser et al., 2024; Tok et al., 2025).

This article aims to provide a comprehensive analysis of the clinical patterns of dental and oral manifestations in CD, with a specific focus on the prevalence and diagnostic implications of enamel defects and MIH. By elucidating these connections, we seek to promote interdisciplinary collaboration between dental and medical professionals to improve patient outcomes and ensure a more holistic approach to the management of CD (Wieser et al., 2023; Bektaş, 2024; Inchingolo et al., 2024).

2. Hard Tissue Manifestations

2.1. Dental Enamel Defects

DEDs are the most frequently documented oral findings in CD (Figure 1), with prevalence rates ranging from 10% to 95.9% (Wieser et al., 2023; Inchingolo et al., 2024). Research consistently demonstrates that children with CD have a significantly higher prevalence of DED compared to healthy controls, with reported rates ranging from approximately 52% to 63.9% in celiac groups versus 16% to 16.1% in control groups (Amirabadi et al., 2024; Acar et al., 2026). DEDs often serve as the only clinical sign of asymptomatic or silent CD, making them valuable non-invasive markers for early diagnosis (Kagioglou et al., 2025; Acar et al., 2026). Furthermore, they are considered highly specific to CD when they appear symmetrically and chronologically across all four quadrants of the permanent dentition, primarily affecting the incisors and first molars (Nardecchia et al., 2019; Alsadat et al., 2021; Inchingolo et al., 2024).



Figure 1. Illustration of DED in a patient diagnosed with CD (Inchingolo et al., 2024)

DEDs are classified into four categories using Aine's criteria: no defects, minor changes (opacities), moderate defects, or severe cases where the tooth shape is altered (Macho et al., 2017; Wieser et al., 2023). Alsadat et al. (2021) provide a comprehensive clinical classification of various DEDs, using a grading system to distinguish severity levels observed in children with CD (Figure 2). Grade I is identified as a qualitative defect in enamel colour, manifesting as white, cream, or brown opacities that can be either well-defined or diffuse in nature. Grade II is classified as a mild structural defect, typically characterised by the presence of shallow pits or horizontal grooves on the enamel surface. Grade III represents a more evident structural defect, including large vertical pits, deep horizontal grooves, or generalised large opacities of varying colours. In its most advanced form, Grade IV, the structural damage is severe enough to alter the tooth's overall morphology, often resulting in pointed cusps.
Pathophysiologically, gluten has been shown to exert direct effects on enamel development and impact the enamel mineralisation process; additionally, calcium malabsorption secondary to CD negatively affects enamel formation, especially during early life (Inchingolo et al., 2024). Crucially, DEDs are permanent and do not regress following the initiation of a GFD, acting as a "retrospective record" of early-life gluten sensitivity (Inchingolo et al., 2024; Tok et al., 2025).



Figure 2. DEDs in individuals diagnosed with CD. a, b and c: Grade I enamel colour defect, d: Grade II mild structural defect, e and f: Grade III evident structural defect (Alsadat et al., 2021).

Beyond clinical identification, DEDs significantly impact the oral health-related quality of life (OHRQoL) in children (Amirabadi et al., 2024). Patients with these defects often report higher scores on quality-of-life impact scales, indicating greater disruption in daily activities such as smiling, socialising, and emotional well-being (Amirabadi et al., 2024). Because DEDs develop during tooth formation, early diagnosis of CD and the timely institution of a gluten-free diet may prevent the development of these defects in permanent teeth (Alsadat et al., 2021; Kagioglou et al., 2025).
Dentists, as oral health specialists, can identify potential CD cases through careful clinical observation and collaborate with gastroenterologists; early recognition of enamel defects, even in the absence of gastrointestinal symptoms, can facilitate timely diagnosis of celiac disease, leading to improved patient outcomes and prompt therapeutic intervention (Inchingolo et al., 2024).

2.2. Molar Incisor Hypomineralization (MIH)

MIH is defined as a qualitative developmental defect of enamel affecting one or more first permanent molars, often involving the permanent incisors (Kuklik et al., 2020; Hoogeveen et al., 2026). Recent research has established MIH as a distinct phenotype within the CD spectrum (Tok et al., 2025). MIH involves hypomineralization of one to four permanent first molars, frequently associated with affected incisors (Wieser et al., 2023). It is clinically characterised by demarcated opacities ranging from white/creamy to yellow/Brown (Figure 3), in which the structural quality of the enamel is compromised due to decreased mineral density (Cristun et al., 2026; Hoogeveen et al., 2026).



a b

Figure 3. Clinical features of molar incisor hypomineralization (MIH). a: Mild MIH with distinct creamy white opacities on the maxillary central incisors. B: MIH with yellow-brown discolourations and post-eruptive enamel breakdown on the incisal edges (Cristun et al., 2026).

Recent studies have identified a significant association between CD and MIH, with prevalence rates in children with CD reported as significantly higher than in healthy controls (Elbek-Cubukcu et al., 2023; Cristun et al., 2026). Cristun et al. (2026) found MIH in 77.1% (27/35) of children with CD, compared with 0% of 35 matched controls, in a Romanian pilot cohort. Furthermore, Elbek-Cubukcu et al. (2023) reported an MIH prevalence of 61% among 62 Turkish children with CD, alongside a significantly higher frequency of recurrent aphthous ulcers in the CD group relative to controls. Similarly, Kuklik et al. (2020) observed MIH in 8 of 40 Brazilian children with CD, compared with 2 of 40 controls, corresponding to a 4.75-fold higher odds of MIH in CD patients (95% CI: 2.22–10.18). Statistical analysis indicates that children with CD are 4.75-8.97 times more likely to exhibit MIH than their healthy peers (Kuklik et al., 2020; Tok et al., 2025). Tok et al. (2025), in the largest cohort reviewed (150 CD patients, 151 controls), reported MIH in 20.7% of children with CD versus 6.0% of controls, with CD conferring an 8.97-fold increased likelihood of MIH.

Clinically, MIH-affected teeth are porous, prone to post-eruptive breakdown (Cristun et al., 2026, Fig. 1b), and frequently associated with dentin hypersensitivity and increased caries risk (Kuklik et al., 2020; Bektaş, 2024; Tok et al., 2025; Hoogeveen et al., 2026). These symptoms significantly diminish the oral health-related quality of life (OHRQoL) in children by causing pain and aesthetic concerns (Amirabadi et al., 2024; Hoogeveen et al., 2026). Because MIH can be the first or only clinical sign of silent or asymptomatic CD, dental professionals play a critical role in early detection, enabling timely multidisciplinary intervention and the implementation of a gluten-free diet (Cicekci et al., 2024; Kagioglou et al., 2025; Tok et al., 2025).

The aetiology of MIH in celiac patients is thought to be linked to systemic metabolic disturbances and malabsorption during critical periods of enamel mineralisation (Cristun et al., 2026). Specifically, strong negative correlations have been identified between MIH severity and serum levels of Vitamin D and Vitamin K2, both of which are essential for calcium homeostasis and amelogenesis (Tok et al., 2025; Cristun et al., 2026). Furthermore, MIH is most prevalent among newly diagnosed or non-compliant children, suggesting that active systemic inflammation and prolonged gluten exposure exacerbate these defects (Tok et al., 2025; Cristun et al., 2026).

2.3. Delayed Dental Eruption (DDE) and Maturation (DDM)

DDE and DDM are recognised as significant extra-intestinal manifestations of CD in pediatric populations (Alsadat et al., 2021; Wieser et al., 2023). Systematic reviews indicate a substantially higher prevalence of these delays in children with CD compared to healthy peers, with one review reporting an overall DDE prevalence of 47.34% in celiac patients versus only 7.85% in control groups (Lucchese et al., 2023). Clinical investigations have observed delayed eruption in approximately 33% to 42.8% of children with biopsy-proven or potential CD, while healthy control groups exhibit significantly lower rates, typically around 11% (Wieser et al., 2023).

The aetiology of DDE and DDM in celiac patients is primarily attributed to malabsorption-induced nutritional deficiencies, specifically of essential micronutrients such as calcium and vitamin D, which are critical during windows of dental development (Avşar and Mobaraki, 2020; Wieser et al., 2023).
Research utilising the Demirjian method for dental age assessment has consistently demonstrated that children with CD exhibit a dental age that lags significantly behind their chronological age (Condò et al., 2011; Avşar and Mobaraki, 2020). This retardation of dental development is most pronounced in children who receive a late diagnosis (after the age of 3), indicating that prolonged exposure to gluten and untreated intestinal damage exacerbate these developmental delays (Avşar and Mobaraki, 2020). This delay is frequently attributed to general growth retardation and nutritional deficiencies, particularly calcium and Vitamin D malabsorption (Macho et al., 2017; Wieser et al., 2023). Interestingly, initiating a GFD has been shown to benefit skeletal and dental development, potentially narrowing the gap between dental and chronological age (Wieser et al., 2023).
Dental age is considered a reliable indicator of general somatic growth and biological age in these patients. The initiation of a stringent gluten-free diet has been associated with a gradual reduction in the delay in dental development from the time of diagnosis, thereby promoting catch-up growth (Wieser et al., 2023). DDE and DDM may serve as the only clinical indicators of silent or asymptomatic CD. Wieser et al. (2023) clearly stated that in patients with undiagnosed CD, these dental symptoms may sometimes be the only presenting features. Similarly, Kagioglou et al. (2025) emphasise that enamel defects can serve as a potential clinical marker for the early identification of atypical or silent cases. Pediatric dentists play a crucial role in the early detection and multidisciplinary management of CD by referring patients with unexplained developmental delays for gastroenterological screening (Wieser et al., 2023; Kagioglou et al., 2025). Additionally, Bektaş (2024) highlights that dentists are instrumental in initiating early diagnosis and treatment by thoroughly assessing oral findings and referring patients to the appropriate specialists.

3. Soft Tissue Manifestations

3.1. Recurrent Aphthous Stomatitis (RAS)

RAS is the most common inflammatory condition affecting the oral mucosa, with a general population prevalence estimated at 5-25%, reaching 60–66% in some cohorts, depending on methodology and population studied (Del Mazo et al., 2023; Aadisha et al., 2026). RAS is characterised by painful, recurrent oral ulcers (Lucchese et al., 2023). Several large-scale reviews confirm a significantly elevated risk of RAS among patients with CD. The prevalence of RAS in CD patients ranges from 31% to 46% (Nardecchia et al., 2019; Wieser et al., 2024). Martín-Masot et al. (2025) reported an overall RAS prevalence of 26.4% among celiac patients, with comparable rates in children (29%) and adults (23%). Consistent with this, Zhao and Feng (2026) pooled 14 studies comprising 1,749 CD patients and 1,775 controls and calculated a pooled relative risk for RAS of 2.45 (95% CI, 1.67–3.60), confirming that individuals with CD are more than twice as likely to develop RAS than non-celiac individuals. Pediatric data corroborate these findings. Acar et al. (2026), in a cross-sectional study of 97 Turkish children with biopsy-confirmed CD, reported a RAS prevalence of 27.8% in the CD group versus 22.5% in healthy controls, with the highest prevalence (47%) observed among newly diagnosed, treatment-naïve patients, suggesting a strong link between RAS and active, untreated disease.
Unlike DEDs, soft-tissue lesions such as RAS often respond favourably to a GFD, with many patients achieving total remission after eliminating gluten (Macho et al., 2017; Wieser et al., 2024). The exact mechanisms linking CD and RAS remain a subject of ongoing research, though several multifactorial pathways have been proposed (Macho et al., 2017; Lucchese et al., 2023). One primary theory attributes the occurrence of oral ulcers to malabsorption-induced nutritional deficiencies. Because CD causes small-intestinal villous atrophy and malabsorption, deficiencies in iron, folate, vitamin B12, and zinc are common and have long been implicated in RAS pathogenesis (del Mazo et al., 2023; Aadisha et al., 2026; Acar et al., 2026).
However, some recent studies have found no direct correlation between RAS and the severity of intestinal damage (Marsh classification) or specific serum micronutrient levels, suggesting that direct immunological responses triggered by gluten exposure may play a more significant role (Lucchese et al., 2023; Acar et al., 2026). Acar et al.

(2026) demonstrated that RAS was significantly more prevalent among newly diagnosed, untreated CD patients than in those on an established gluten-free diet (GFD), and that 44.2% of affected children experienced remission following GFD implementation. Similarly, Martín-Masot et al. (2025) cite multiple primary studies reporting that RAS episodes improve or resolve after adoption of a GFD, with the greatest improvement observed at 12–24 months of dietary adherence. However, the authors caution that the underlying studies are largely observational (retrospective cohorts and cross-sectional designs) and thus provide only limited-quality evidence.

Genetic predisposition, particularly the presence of the HLA-DQ2 haplotype, has also been associated with an increased frequency of RAS in celiac patients (Acar et al., 2026). Martín-Masot et al. (2025) note conflicting evidence regarding HLA-DQB1*02 as either protective or a risk factor across different cohorts, alongside reports of increased DRw10 and DQw allele frequencies in celiac patients with RAS. The introduction of a strict gluten-free diet is considered the most effective intervention, with numerous studies reporting significant remission or complete disappearance of RAS lesions with dietary adherence (Macho et al., 2017; Nardecchia et al., 2019; Acar et al., 2026). Because oral lesions can precede classic gastrointestinal symptoms, they serve as essential risk indicators for undiagnosed CD (Alsadat et al., 2021; Wieser et al., 2023).

Because RAS frequently improves with gluten withdrawal and is disproportionately common in active, untreated CD, clinicians—particularly dentists and gastroenterologists—should consider CD in the differential diagnosis of recurrent or atypical oral ulceration. At the same time, additional prospective, standardised studies are needed to clarify causal pathways and optimise management.

3.2. Other Mucosal Manifestations

Atrophic glossitis is defined by a smooth, shiny, and red tongue resulting from papillary atrophy (Figure 4), frequently associated with iron or vitamin B12 deficiencies (Macho et al., 2017; Lucchese et al., 2023). This condition is primarily attributed to malabsorption-induced deficiencies of iron, folate, and vitamin B12 (Pastore et al., 2007; Macho et al., 2017; see Figure 5). In some cases, atrophic glossitis has been reported as the sole clinical indicator of undiagnosed CD, with symptoms typically resolving within one month of initiating a strict gluten-free diet (Pastore et al., 2007; Lucchese et al., 2023).



Figure 4. Erythematous, Atrophic Region on the Dorsal Surface of the Tongue (Pastore et al., 2007).



Figure 5. Atrophic glossitis and angular cheilitis in a patient with celiac disease and serum iron deficiency (Martín-Masot et al., 2025).

Inflammatory conditions such as geographic tongue and angular cheilitis are observed more frequently in individuals with CD than in healthy controls (Lucchese et al., 2023; Bektaş, 2024). Geographic tongue, an immune-mediated inflammatory lesion, has been observed in approximately 6.7% to 15% of celiac patients (Macho et al., 2017; Lucchese et al., 2023). Angular cheilitis, manifesting as erythema and crusting at the corners of the mouth, is often linked to B-complex vitamin or iron deficiencies linked to malabsorption (Martín-Masot et al., 2025; Zhao and Feng, 2026). Additionally, up to 38% of patients with CD report xerostomia, a sensation of dry mouth, which may be related to alterations in the salivary glands or be associated with Sjögren's syndrome (Cruz et al., 2018; Lucchese et al., 2023).

Sensory disturbances, such as glossodynia (burning tongue sensation), have also been reported and are often secondary to the same hematologic deficiencies that drive atrophic glossitis (Pastore et al., 2007; Lucchese et al., 2023). These mucosal signs provide essential diagnostic clues, especially in atypical or "silent" forms of the disease where classic gastrointestinal symptoms are absent (Wieser et al., 2023; Bektaş, 2024; Acar et al., 2026).

4. Etiopathogenesis of Oral Manifestations

The mechanisms linking CD to dental defects are complex and encompass both nutritional and immunological factors (Inchingolo et al., 2024; Wieser et al., 2024). Nutritional malabsorption resulting from intestinal villous atrophy impairs the uptake of essential micronutrients such as calcium, phosphorus, and vitamin D, all of which are vital for amelogenesis (enamel formation) (Tok et al., 2025; Wieser et al., 2023). In addition, autoimmune cross-reactivity has been proposed, in which gluten-induced antibodies—particularly anti-gliadin IgG—may cross-react with enamel matrix proteins such as amelogenin and ameloblastin, thereby disrupting the normal function of ameloblasts during tooth development (Lucchese et al., 2023; Wieser et al., 2023; Bektaş, 2024). Genetic factors, including the presence of HLA-DQ2/DQ8 haplotypes and other genetic markers, may also modulate the severity and clinical presentation of dental symptoms in individuals with CD (Macho et al., 2017; Inchingolo et al., 2024).

5. Diagnostic Significance and the Dentist's Role

The oral cavity often serves as a unique diagnostic window into systemic health, and in celiac disease (CD), it may provide the first, or even the only, clinical indicators of the condition (Inchingolo et al., 2024; Lucchese et al., 2023). Dental professionals, particularly pediatric dentists, occupy a strategic position in the early identification of CD because dental enamel development occurs in early childhood; the presence of specific DEDs or MIH can lead to a diagnosis of CD even in the absence of gastrointestinal symptoms (Inchingolo et al., 2024; Wieser et al., 2023). Dentists and pediatric dental specialists serve as sentinels for the early detection of unrecognised CD (Paul et al., 2016; Inchingolo et al., 2024). Identifying symmetrical enamel defects should prompt a thorough medical history and referral to a gastroenterologist for serological screening (anti-tTG and EMA antibodies) and, if indicated, a biopsy (Rubio-Tapia et al., 2023; Wieser et al., 2023). Early diagnosis is critical; while a GFD cannot reverse enamel damage, it can prevent severe systemic consequences, including osteoporosis, refractory anaemia, and increased malignancy risk (Wieser et al., 2024; Doyle et al., 2025). The role of the dentist extends beyond detection to facilitating a multidisciplinary management framework. Early diagnosis facilitated by dental professionals is vital for the timely implementation of a strict gluten-free diet, which can prevent irreversible systemic complications such as growth retardation, osteoporosis, and even certain malignancies (Amirabadi et al., 2024; Bektaş, 2024; Inchingolo et al., 2024). Dentists must remain vigilant, questioning the clinical history of patients presenting with persistent oral ulcers or specific enamel defects and referring them to paediatricians or gastroenterologists for serological and histological screening (Bektaş, 2024; Cicekci et al., 2024; Wieser et al., 2023). By bridging the gap between oral and systemic health care, dentists play a crucial role in improving long-term oral health-related quality of life and the overall prognosis for patients with celiac disease (Amirabadi et al., 2024; Hoogeveen et al., 2026).

CONCLUSIONS

The dental and oral manifestations of CD serve as critical early clinical markers that often precede systemic diagnosis. Permanent conditions such as symmetrical DED and MIH provide a retrospective indication of early-life gluten sensitivity, underscoring the importance of timely recognition. Early identification of these patterns enables prompt intervention and the initiation of a lifelong gluten-free diet, which is essential for systemic health and the management of mucosal lesions. Dentists play a crucial role in early detection and prevention of irreversible complications through vigilant clinical assessment and appropriate referral.

Future perspectives should focus on strengthening interdisciplinary collaboration between dental and medical professionals to enhance early detection and comprehensive management of CD.

Further research is needed to elucidate the precise immunological mechanisms underlying these oral manifestations and to develop standardised diagnostic protocols that incorporate dental screening for at-risk populations. Additionally, longitudinal studies assessing the impact of early gluten-free diet initiation on the prevention of dental defects and on improving oral health-related quality of life will be valuable. Increasing awareness and education among dental practitioners will reinforce their role as frontline sentinels, ultimately improving systemic outcomes and holistic patient care.

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ATATÜRK'ÜN DÜŞÜNCE DÜNYASININ ANALİZİNE BİR ÖRNEK: "KARLSBAD HATIRALARI"

AN EXAMPLE OF THE ANALYSIS OF ATATÜRK'S WORLD OF THOUGHT: "MEMORIES OF KARLSBAD"

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ÖZET

Gazi Mustafa Kemal Atatürk'ün düşünce sistemi sadece bir ulusun kaderini değiştiren bir kurtuluş mücadelesi değil, aynı zamanda çağdaş bir devlet olmanın temelini de oluşturmuştur. Atatürk'ün düşünce dünyasına yön veren etkenler, yaşadığı zaman dilimindeki olaylar, okul hayatı, okuduğu kitaplar, yaşadığı şehirler, görev aldığı ülkeler, katıldığı manevralar şeklinde özetlenebilir. Tüm yasaklamalara rağmen öğrencilik yıllarında Fransız Devrimi hakkında ilk bilgileri edinmiş, yabancı dilini geliştirmesi sayesinde dünyada olup bitenleri izleme olanağına kavuşmuştu. Batılı ülkelerde katıldığı askeri manevralar sayesinde Avrupa'yı oldukça yakından tanıma fırsatı olmuştu. Katıldığı savaşlarda ise Batı'nın öbür yüzüyle, uygar görünüşü altındaki sömürgeci yanıyla karşı karşıya kalmıştı. Tüm bu analizler, Mustafa Kemal Atatürk'ü o dönemde kimsenin adını koyamadığı ulusal değerlere ve çağdaş ilkelere dayanan yeni bir Türkiye'nin kurulmasını düşünmeye sürüklemiş ve O'nun düşüncesinin temelini oluşturmuştu.

Atatürkçü düşünce sistemine dair bir değerlendirme yaparken kaleme aldığı eserlerin özellikle hatıratlarının analizi O'nun fikirlerini anlamada önemli bir veri sunmaktadır. Mustafa Kemal Atatürk, tedavi olma amacıyla gittiği Karlsbad'da, "*Karlsbad Hatıraları*" olarak bilinen bir günlük tutmuştur. Söz konusu günlükte Atatürk'ün özel yaşamına dair bilgiler yer almaktadır. Tuttuğu notlar sayesinde prensipleri, alışkanlıkları, yaşadığı dönemin sorunlarına dair ürettiği çözüm önerileri anlaşılabilmekte geleceğe dair planları hakkında analiz yapılabilecek veriler sunmaktadır. Atatürk'ün düşünce dünyasına ilişkin önemli bir kaynak olan hatıratı, Birinci Dünya Savaşı'nın sonlarına yaklaşıldığı oldukça zorlu bir dönemde geleceğe dair çağdaş uygarlık düzeyine ulaşma ideallerine de ışık tutması nedeniyle önemlidir.

Anahtar Kelimeler: Mustafa Kemal Atatürk, Atatürk'ün Fikirlerinin Analizi, Hatırat, Karlsbad Hatıraları

ABSTRACT

Gazi Mustafa Kemal Atatürk's system of thought not only constituted a liberation struggle that cganged the destiny of a nation, but also laid the foundation for becoming a modern state. The factors that shaped Atatürk's intellectual World can be summarized as the events of the period in which he lived, his school life, the boks he read, the cities he lived in, the vountries where he served and the military maneuvers he participated in. Despite all prohibitions, he obtained his first information about the French Revolution during his student years and by improving his foreign language skills, he gained the opportunity to follow what was happening in the world. Thanks to the military maneuvers he attended in Westwen countries, he had the chance to become closely acquainted with Europe. In the wars he participated in, he encountered the other face of the West, its colonialist side beneath its civilized appearance. All these analyses led him to think about the establishment of a new Turkey based on national values and modern principles, which no one at the time had been able to define and formed the foundation of his ideas.

When making an assessment of Atatürk's system of thought, the analysis of the works he authored, especially his memoirs, provides an important source of data for understanding his ideas. Mustafa Kemal Atatürk kept diary during his stay in Karlsbad, where he had gone for treatment, known as the "Karlsbad Memories". This diary contains information about Atatürk's private life. Thanks to the notes he kept, it is possible to understand his principles, habits and the solutions he developed for the problems of the period in which he lived, while also providing data that allows for analysis of his plans for the future.

His memoir which is an important source regarding Atatürk's world of thought, is significant because it sheds light on his ideals of reaching the level of contemporary civilization in the future, during a very difficult period when the First World War was still ongoing.
Keywords: Mustafa Kemal Atatürk, Analysis of Atatürk's İdeas, Memoir, Memories of Karlsbad.

Giriş

Gazi Mustafa Kemal Atatürk'ün düşünce dünyasını şekillendiren olaylara yönelik bir analiz yaparken aynı zamanda liderin mi şartları belirlediği yoksa şartların mı bir lideri ortaya çıkardığı sorusu üzerinde bir değerlendirmeye yönelmek de mümkündür. Atatürk'ün yaşadığı zaman dilimindeki olaylar, doğduğu coğrafya, okul hayatı, okuduğu kitaplar, yaşadığı şehirler, görev aldığı ülkeler, katıldığı manevralar O'nun yüksek potansiyelinin ve kişisel meziyetlerinin yanında fikirlerine yön veren katmanları oluşturduğu söylenebilir.

Yaşadığı döneme bakılacak olursa, oldukça önemli bir tarihsel dönemeç olan Fransız İhtilali'nin etkilerinin dünyada hissedildiği, insan hakları, özgürlük, bağımsızlık ve ulusçuluk gibi kavramların Avrupa'dan Asya'ya yayılıp etkilerinin Osmanlı Devleti gibi çok uluslu bir devleti etkilediği hatta parçalayıp çöküşüne yol açacak bir döneme evrildiği zaman dilimidir. 1830 ve 1848 tarihleri Fransa'da başlayarak domino etkisiyle diğer ülkelere de dalgalar halinde yayılan ihtilallerin yaşandığı bir dönemdir. Bu dönemde Avrupa ülkelerinde krala ve baskıya karşı halk ayaklanmış, işçi hakları, liberalizm öne çıkmış, parlamenter sistemin temelleri atılmıştır. İhtilal bağımsızlık ve ulusal birlik akımını gerçekleştirme konusunda amacına ulaşamamış olsa da Avrupa'da birçok hükümdar tahttan uzaklaştırılmış, liberal bir yönetimi kabul etmek durumunda kalmıştır. Neredeyse tüm Avrupa'da derin etkiler bırakmış olan 1848 İhtilalleri, benzer biçimde Balkan coğrafyasını da etkisi altında kalmıştır[1]. 1860'lı yıllar Osmanlı aydınlarının Fransa'ya kaçarak burada anayasa, meşrutiyet ve parlamento gibi isteklerini yazmalarına zemin hazırlamıştır. Dolayısıyla bu dönem, Avusturya-Macaristan, Rusya gibi imparatorlukların yanında çok uluslu yapısı nedeniyle Osmanlı Devleti'ni de derinden sarsan bir dönem olmuştur. 1804 tarihli Sırp İsyanı diğer ayrılıkçı faaliyetleri de tetiklemiş, ondan hemen sonra daha geniş kapsamlı olarak 1821 tarihli Yunan İsyanı çıkmış, iki beylik halinde yönetilen ve Romanya birliğinin kurulması için güçlü bir akımın bulunduğu Eflak ve Buğdan da aynı tarihte ayaklanmıştır. Osmanlı Devleti 1853'te Karadağ İsyanı 1875'te ise Bosna-Hersek İsyanı, 1876'da Bulgaristan, 1908'de de Arnavutluk isyanı ile karşı karşıya kalmıştır. Balkanların dinamizmiyle yaşayan bu coğrafyanın çocukları hem Batı'yı takip edebilmekteydiler hem de kendi ülkelerinin içinde bulunduğu buhranı gözlemleyebilmekteydiler[2].

Mustafa Kemal Atatürk'ün doğduğu şehir Selanik, Osmanlı coğrafyasının kozmopolit, modern, üç kıta arasındaki ticaret yollarının kesiştiği önemli bir liman kenti olmakla birlikte aynı zamanda devletin Batı'ya açılan kapılarından biriydi. Osmanlı yönetimi, Batı'ya yönelirken modernleşme girişimlerini Rumeli'de başlattığı için Selanik öncelikli şehirlerden biri olarak bu imkanlardan da faydalanmıştı. 1889'da demiryolu ile Sırbistan üzerinden Viyana ile Bulgaristan üzerinden Başkent İstanbul ile bağlantılıydı[3]. Mustafa Kemal'in eğitim gördüğü Selanik ve Manastır'da pek çok görüşü temsil eden gazeteler yer almaktaydı. Balkan coğrafyasında eğitim gören Harp okulu öğrencisi olarak 19. yüzyılın felsefi akımlarından haberdardı. Gayrimüslim kadınlar ile sokağa özgürce çıkamayan Müslüman kadınlar arasındaki farkı gözlemleyebilme imkanına sahipti.

Mustafa Kemal Atatürk'ün yaşadığı zaman dilimindeki olaylar ve doğduğu coğrafya kadar okul hayatı da düşünce dünyasının şekillenmesine katkı sağlamıştır. Okul yıllarında başarılı bir öğrenci olan Mustafa Kemal, Selanik Askeri Rüştiyesi'nde okurken özellikle matematik derslerinde gösterdiği başarıdan ötürü hem sınıf müzakerecisi olmuş hem de öğretmeni tarafından yetkinlik, olgunluk anlamına gelen Kemal adı eklenmişti. Daha sonraki yıllarda Geometri kitabını yazacaktır. Fransızca öğretmeni Yüzbaşı Nakiyüddin Yücekök sadece Fransızca öğretmekle kalmamış, ülkenin geleceği ile ilgili düşünceleri de aşılamıştı[4]. İleriki yıllarda kendisinden yardım göreceği hocası TBMM'de milletvekili

[1] Rıfat Uçarol, *Siyasi Tarih*, Filiz Kitabevi, İstanbul 2000, s. 128.
[2] Lord Kinross, *Atatürk-Bir Milletin Yeniden Doğuşu*, Altın Kitapları, İstanbul 2021, s.18.
[3] Şerafettin Turan, *Mustafa Kemal Atatürk*, Bilgi Yayınları, Ankara 2017, s.39.
[4] George W. Gawrych, *Osmanlı Zabitinden Türk Devlet Adamına Genç Atatürk*, Doğan Kitap, İstanbul 2014, s.23.

olarak yer alacak, alfabe devrimine katkı sunacaktır. Manastır Askeri İdadisi, Mustafa Kemal'in entelektüel ve toplumsal gelişiminde büyük katkısı olmuştur. Okulda tarih derslerini sevmesinde öğretmeni Tevfik Bilge etkili olmuştu. Hocasına her zaman saygı duyan Mustafa Kemal, Cumhuriyetin ilanı sonrasında kendisine olan vefasını göstermiştir. 1932 tarihinde Tevfik Bilge Türk Tarih Kurumu üyesi olacaktır. Okulda şair ve hatip olarak tanınan arkadaşı Ömer Naci sayesinde şiir ve edebiyatla ilgilenmeye başlamış, yeni arkadaşlarından Fethi Okyar ise Fransız yazarların temsil ettiği Fransız siyasal düşüncesini tanımasını sağlamış, Fransızcasını ilerletmek için okuduğu kitaplarda devrim, bağımsızlık, özgürlük kavramlarını özümsemesine yardımcı olmuştu. Kazım Özalp ile tanışıklığı da bu dönemde olmuştur[5]. Henüz Askeri Rüştiye'de iken dansa merak salan Mustafa Kemal, arkadaşı Fuat Bulca ile dans dersleri yanında Fransızcasını ilerletmek için dans okuluna gitmişlerdir[6].

Okul yıllarının dışında da okumalarına devam edecek, okuduğu kitaplar düşünce dünyasının şekillenmesinde etkili olacaktır. Mustafa Kemal için 1899'da Harp Okulu dönemi ile İstanbul yılları başlamış, istibdat yönetiminin sakıncaları ve ülkenin geleceği konusundaki düşüncelerle meşgul olmaya başlamıştır. Harbiye'de okurken özellikle talim ve terbiye dersleri veren Yüzbaşı Naci Eldeniz hocasına karşı büyük bir saygı duyuyordu. Vahdettin padişah olduğunda başyaverliğe atanmıştı. Kurtuluş Savaşı döneminde Mustafa Kemal Paşa'ya destek verecek olan hocası Cumhuriyet döneminde korgeneralliğe kadar yükselecektir. Tanınmış bir aileye mensup olan Ali Fuat Cebesoy ile arkadaşlığı bu dönemde başlamıştır. Refet Bele, Cafer Tayyar Eğilmez, Nuri Conker, Mehmet Arif (Ayıcı) dönem arkadaşları arasındaydı. Kazım Karabekir bir alt sınıfta, İsmet İnönü ise ondan iki yıl sonra Harbiye'ye girmişti[7]. Yabancı dilini ilerletmek için dersler almaya devam etmiş, bilgi alanını genişletmek için Fransızca gazeteleri takip etmiştir[8].

Okuldan mezun olduktan sonra kendisine verilen görevler nedeniyle bulunduğu coğrafyalar ve katıldığı manevralardaki izlenimleri de düşünce dünyasının şekillenmesine etki etmiştir. İlk görevi olan Şam'a tayini, O'nu hedef noktasından uzak bırakmış olsa da planlarına engel oluşturmamış, Vatan ve Hürriyet Cemiyeti'ni kurarak gizli yollarla gittiği Selanik'te de örgütün şubesini açmıştır. Koşulların zorluğuna bakmaksızın teşkilat kurmuş olması, örgütlenmenin O'nun için ne kadar önemli olduğunun bir göstergesiydi. Henüz 1906 tarihinde kurduğu örgütün adı da düşünce dünyasına dair analiz yapmak adına büyük önem taşımaktadır. "Ancak hür fikirli insanlardır ki vatanlarına faydalı olurlar" diyecek daha sonra bu anlayış "hürriyet ve özgürlük benim karakterimdir" biçiminde bir ilkeye dönüşecektir.

Mustafa Kemal Atatürk'ün hedefleri konusundaki kararlılığının yanında ilkeleri konusundaki tutarlılığını gösteren bir başka örnek İttihat ve Terakki Cemiyeti'ne katıldıktan sonra ordu ve cemiyetin içiçe geçmesine yönelik eleştirilerini açıkça söylemekten çekinmeyen duruşu olmuştur. Savunduğu görüşleri nedeniyle cemiyet tarafından çok sert tepkilerle karşılaşınca cemiyetle ilişkilerini koparacaktır. Parti liderleri, devletin Birinci Dünya Savaşı'na girmesine taraftar iken Mustafa Kemal savaşa mümkün olduğunca geç girme fikrinde olmuş, Almanların savaşta başarılı olacaklarına dair partinin kanaatine inanmamış ancak fikirlerini kendisine muhalif olanlara da kabul ettirememiştir. Savaş döneminde görev yeri olan Sofya'da kalmayı uygun görmeyerek bütün enerjisi ve vatanseverliğiyle etkin bir görevde bulunmak üzere Harbiye Nezareti'ne başvurmuştur[9]. Çanakkale Savaşı'nda inisiyatifi ele alarak gösterdiği başarı ünlenmesini sağlamış, sonrasında Diyarbakır'daki 16. Kolordu Komutanlığına atanarak Ruslardan Muş ve Bitlis'i geri alması, savaşın diğer bir başarısı olarak komutanlığını yeniden öne çıkartmıştır. 1916'da tuğgeneralliğe terfi etmiş, paşa unvanını almıştır. Türk ordusunun Almanların elinde kötü yönetildiğine dair görüşleri nedeniyle Alman komutanlarla anlaşmazlık yaşamış, 1917 tarihli Harbiye Nezareti'ne gönderdiği eleştirilerinin aynı zamanda analizlerinin ve önemli tavsiyelerinin yer aldığı raporlarından bir sonuç alamayınca istifa edip İstanbul'a gitmiştir. Aralık 1917'de Veliaht Vahdettin ile Almanya seyahatine katılmış ancak Almanya'nın savaşı kazanma ihtimali konusundaki kuşkuları daha da güçlenmiş ayrıca Vahdettin'i de hiç etkileyici bulmamıştı.[10]

[5] *A.g.e.*, s.23-24.
[6] Turan, a.g.e., s.46.
[7] Turan, a.g.e., s.48.
[8] Kinross, a.g.e., s.32.
[9] *A.g.e.*, s.91.
[10] Falih Rıfkı Atay, *Çankaya*, Pozitif Yayınları, İstanbul 2004, s.117.

Mustafa Kemal Paşa'nın seyahat öncesi yaşadığı böbrek rahatsızlığı seyahat sonrasında da devam etmiş, birkaç ay süren rahatsızlığı nedeniyle tedavi görmek üzere Viyana'ya gitme izni almıştır. İstanbul'dan ayrılmadan önce basına uzun bir röportaj verme fırsatı olmuş, Yeni Mecmua'da üç gün boyunca yayınlanan mülakatında Çanakkale'deki başarılarını ayrıntılı bir biçimde dile getirmiştir[11]. Karlsbad'da bulunduğu dönemde fikirlerini anlamaya imkân tanıyan Karlsbad Günlüklerini tutmuştur.

Atatürk'ün Yazdığı Kitaplar

Gazi Mustafa Kemal Atatürk'ün fikir dünyasının oluşumunda en önemli etkenlerden biri her fırsatta kitap okuma alışkanlığına sahip olmasıdır. Bu özelliği O'nun etkili hitabetine de katkı sunmuş, bu merakı ve yeteneği günlük tutma alışkanlığına dönüşmüş, sonrasında belge niteliği taşıyan eserler yazmasıyla devam etmiştir. Geride bıraktığı eserlerine bakılacak olursa günlükleri, mektupları, söylev ve demeçleri, telgrafları, beyannameleri, raporları, çevirileri, yazdığı kitapları çerçevesinde değerlendirmek mümkündür.

Atatürk'ün ilk kaleme aldığı kitapları, askerlik mesleği ile ilgili yazdıkları ve çevirilerini yaptığı kitaplardır. 1909'da Takımın Muharebe Talimi, Cumalı Ordugahı, 1911'de Beşinci Kolordu Erkan-ı Harbiye Tabiye Tatbik ve Seyahati, 1912'de Bölüğün Muharebe Talimi, 1916'da Taktik Meselesinin Çözümü ve Emirlerin Yazılmasına İlişkin Öğütler ve Talim ve Terbiye-i Askeriyye Hakkında Nokta-i Nazarlar, 1918'de Zabit ve Kumandan ile Hasbihal, Anafartalar Muharebatına Ait Tarihçe, 1917'de Arıburnu Muharebeleri Raporu, askeri konuları içeren yayınlarıdır.

Güneydoğu'da 16. Kolordu Komutanı iken kasım-Aralık 1916 tarihleri arasında tuttuğu notları içeren ve o tarihteki yaveri Yedek Subay Şükrü Tezer'e verilen günlüğü "*Atatürk'ün Hatıra Defteri*" adıyla yayımlanmıştır. Ayrıca Harp Okulu öğrencilik yıllarında başlayıp 1933 tarihine kadar kendisi tarafından yazılmış olan defterleri, Genelkurmay Askeri Tarih ve Stratejik Etüt Başkanlığı tarafından "*Atatürk'ün Not Defterleri*" adıyla yayımlanmıştır[12].

Atatürk'ün yazım yeteneklerini propaganda amaçlı kullandığı dönemler de olmuştur. Örneğin okul yıllarında arkadaşlarıyla birlikte gizli olarak elle hazırlanmış bir gazete çıkarmışlardır[13]. Sonraki yıllarda basının kamuoyu oluşturmadaki rolünün savaş döneminde ihmal edilemeyecek önemlilikte olduğu gerçeğinden hareketle Anadolu'ya geçmeden önce İstanbul'da çıkardığı Minber Gazetesi, propaganda faaliyetlerini yürütmede oldukça etkili olmuştur. Anadolu'ya geçince benzer düşünceyle milli birliği sağlamak adına basının gücünü en etkin biçimde kullanmaya devam etmiştir. Cumhuriyet döneminde de takma isimle gazetelere makale yazığı bilinmektedir.

Tarihi yapanın kaleme aldığı belge niteliğindeki en bilinen eseri, 15-20 Ekim 1927 tarihinde Cumhuriyet Halk Fırkasının kongresinde söylediği ve 1928 tarihinde de farklı dillerde de çevirilerinin yapıldığı "*Nutuk*" adlı eseridir[14]. Devletin kurucusu tarafından Kurtuluş Savaşı Dönemi ile birlikte Cumhuriyetin ilk beş yılının bilançosunun çıkarıldığı, bir başka deyişle "*kurucunun milletine hesap verdiği*" Nutuk adlı eseri 36 saat 31 dakikalık okunuş süresi bakımından da özel bir öneme sahiptir. Kasım 1930-Mart 1931 tarihlerini kapsayan yurt içi gezilerinde ülkenin sorunlarına yönelik çözüm önerilerini içeren raporlar hazırlamıştır[15]. 1931 tarihinde orta öğretimde okutulan "*Vatandaş İçin Medeni Bilgiler*" kitabı büyük oranda Atatürk'ün yazdığı hem de Afet İnan'a yazdırdığı notları içermektedir. Bir diğer eseri ise 1936-37 tarihleri arasında matematik öğretmenleri ile birlikte matematik terimlerini Türkçeleştirmek üzere hazırladıkları "*Geometri*" adlı kitabıdır. Bu çaba eğitim dilini Türkçeleştirmek ile birlikte Türkçenin bir bilim dili olabileceğine dair bir ideali içermektedir.

Mustafa Kemal Atatürk'ün "*Karlsbad'da Geçen Günlerim*" başlığı ile tuttuğu notları, Atatürk'ün tedavi için gittiği o dönemde Avusturya Macaristan sınırları içerisinde olan günümüzde ise Çek Cumhuriyeti sınırları içerisinde yer alan kaplıcalarıyla ünlü Karlsbad'da tuttuğu günlüğüdür.

[11] Gawrych, a.g.e., s.87

[12] Hakan Uzun, "*Yazdığı Eserlerde Atatürk'ü Tanımak ve Anlamak: M.Kemal Atatürk'ün Karlsbad Hatıraları*", Ankara Üniversitesi Türk İnkılap Tarihi Enstitüsü Atatürk Yolu Dergisi, sayı.59, Güz 2016, 168.

[13] Turan, a.g.e., s.53.

[14] Malike Bileydi Koç, Atatürk İlkeleri ve Devrim Tarihi, "*Atatürk'ün Büyük Nutku Üzerine Notlar*", Tarihçi Yayınevi, İstanbul 2010, s. 305.

[15] Gürbüz Tüfekçi, *Atatürk'ün Seyahat Notları (1930-1931),* Kaynak Yayınları, İstanbul 1998, s.76.

30 Haziran-28 Temmuz 1918 tarihleri arasında tuttuğu günlüğünde tedavisi, okuduğu kitapları, görüştüğü insanlarla yaptığı sohbetlerinin içeriği, ülkenin askeri, siyasal, sosyal sorunlarına ve geleceğine dair düşünceleri yer almaktadır. Günlük eski harflerle tutmuş olmasına rağmen bazı sayfaları Fransızca yazılmış, yabancı isimler Latin harflerle belirtilmiştir. Ayşe Afet İnan tarafından yayımlanan hatıraları, Mustafa Kemal Atatürk'ün kişisel özelliklerine dair bir değerlendirme yapma imkânı sunmaktadır.

Mustafa Kemal Atatürk'ün Karlsbad Hatıraları

Mustafa Kemal Paşa'nın yıllarca süren böbrek rahatsızlığı nedeniyle Almanya dönüşünde yeniden sancıları tekrarlamış, Pera Palas'ta kendisini muayene eden doktorlar, sol böbreğinde iltihap saptayınca yaklaşık bir ay yataktan çıkamamıştır. Bu arada Almanya'daki olumsuz izlenimlerine rağmen Alman Büyükelçiliği'nde düzenlenen 19 Şubat 1918 tarihli törende kendisine "cordon de prusse" nişanı verilmişti. Etkin bir görev verilmesini beklerken 28 Mart 1918 tarihinde Ruşen Eşref Ünaydın ile üç gün süren bir mülakat yapmış, söyleşi "Yeni Mecmua"nın "Çanakkale" özel sayısında yayımlanmıştı. Böbrek rahatsızlığının devam etmesi Avrupa'da tedavi görmesini gerekmiştir. Mustafa Kemal Paşa aldığı izin ve ödenekle 25 Mayıs 1918 tarihinde Emireri Şevki ile birlikte Viyana'ya hareket etmişti. 5 Haziran tarihinde Dr. Rasim Ferit Talay'a gönderdiği mektubunda, "*sizce malum olan rahatsızlığım burada Dr. Buyes'in tavsiyesiyle başvurduğum Profesör Zuckerkandl tarafından da aynen kabul edildi. Kolibasilinden başka bir şey bulunamadı. Cottage Senotoryumuna girdim. Profesör bizzat tedavi ediyor. Üç hafta burada kaldıktan sonra üç hafta da kür için bir banyoya gitmeyi tavsiye ediyor. Rahatım iyidir, ıstırabım yoktur. Eşyalarım kayboldu. Çırılçıplak kaldım"*[16] cümleleriyle durumunu izah edecektir. Mektuptan anlaşılacağı üzere Viyana'daki doktorları da rahatsızlığına aynı teşhisi koymuştur. Viyana'ya indiklerinde bavullarının kaybolması üzerine ilk önce kendisine yeni bir takım elbise, bir fötr şapka, gözlük ve kıyafet almak zorunda kalmıştı[17]. Orta halli bir aileden gelmiş olmasına rağmen, nerede nasıl davranması gerektiğini bilen, bulunduğu yere uyum sağlayan, dış görünüşüne son derece önem veren bir kişiliğe sahip olduğu anlaşılmaktadır.

Mustafa Kemal Paşa önce Viyana'da Bristol Oteli'ne yerleşmiş, Cottage Sanatoryumunda tedavi görmüş, ilk tedavisinin ardından kaplıca tedavisine başlamak üzere sevk edilmiş, 30 Haziran tarihinde trenle Karlsbad'a geçmiştir[18]. Viyanalı hekimler aracılığıyla önceden bulunan Rudolfs Hof adlı konağın bir dairesine yerleşmiştir. Anılarında pek beğenmediğini belirttiği bu daire bir salon, iki oda ve bir hamamdan oluşmaktaydı. Daireyi kendi ihtiyaçlarına göre düzenlemiş, salonun yanındaki bir küçük odayı, çalışma odası yapmak üzere kendi dairesine dahil etmiştir. Not defterine geldikten bir gün sonra 2 Temmuz Salı günü yürüyüş yaptığı sırada bir çiçekçi kadına rastladığını yazarak şöyle devam etmiştir; "*Birkaç buket kırmızı ve beyaz karanfil ve adını bilmediğim diğer bir çiçek aldım. Fakat sonra bunlar için bir vazo lazım olduğunu düşündüm. Tam yanı başımda bir mağazaya girdim. Büyük, küçük dört vazo aldım. Eve geldim. Çiçekleri vazolara Şevki ile beraber yerleştirdim. Vazoları salona, büroya dağıttım*".[19] Elinde birden fazla buketle yaptığı yürüyüş, bulunduğu mekânı çiçeklerle güzelleştirme isteği, onun ince bir ruha sahip olduğunu göstermektedir. Mustafa Kemal Atatürk'ün Cumhuriyet dönemindeki faaliyetlerine bakılınca Yalova'daki Yürüyen Köşk örneğinde olduğu gibi çevreye duyarlı bir lider olduğuna dair pek çok örnek verilebilir. Aynı günün akşamı Albay Emin Bey ve eşi ile Otel İmperial'de akşam yemeği esnasındaki sohbetlerini not defterine "siyaset" başlığı ile not etmiş ve öngörüsünü şu şekilde ifade ettiğini aktarmıştır; "*Almanların bize gerek bu hususta (Bulgaristan'dan toprak talebi) ve gerek memleketimizi İngiliz istilasından kurtarmada yardımlarının derecesini mantıken meydana çıkarabiliriz. Benim bu hususta daima olumsuz neticelere varan kanaatlerim, Veliaht hazretleri ile gerçekleşen seyahatimiz münasebetiyle gerek imparator gerek Hindenburg ve Ludondorf'la olan konuşmalarla doğrulanmıştır. Bir devletin yetkilileri kendi insani hislerine bağlı olarak devlet meselelerini halledemez, o yetkiye sahip değildir. Memleket kimsenin malikanesi değildir. Yalnız biz Türkler memleket ve milletin idaresini elimize aldığımız zaman, kendi şahsi işlerimizde gösterdiğimiz cömertliği, devlet meselelerini ve işlerini yabancılarla çözerken kural olarak alıyor, bir*

[16] *Atatürk'ün Bütün Eserleri*, c.2, Kaynak Yayınları, İstanbul 2009, s.171.
[17] Turan, a.g.e., s.157.
[18] Kinross, a.g.e., s.146.
[19] Mustafa Kemal Atatürk, *Karlsbad Hatıraları*, Kaptan Yayınevi, Ankara 2023, s.48.

çocuk gibi aldanıyoruz"[20]. Mustafa Kemal Paşa, Almanya gezisi esnasında yaptığı cephe incelemesi ile savaşın başından itibaren Almanlara karşı olumsuz düşüncesini teyit etmiş, bu fikrini ve öngörüsünü sohbet esnasında da tekrar dile getirmiştir. Bu diyalogdan Atatürk'ün inandıklarını açıkça ifade ettiği ve öngörülerinde de haklı çıktığı görülmektedir.

Karlsbad günleri şu nedenlerle önemlidir; bu zoraki dinleniş Mustafa Kemal Paşa'ya yeniden kitap okuma ve ülkesinin geleceği üzerindeki düşüncelerini bir düzene sokma imkânı verdiği gibi içinde bulunduğu döneme ait siyasi görüşlerinin yanında geleceğe ilişkin planlarını not ettiği bir hatıra defteri tutmasına da fırsat tanımıştır. Böylelikle hem kendini dinlemeye hem de ülkenin ve dünyanın içinde bulunduğu durumu savaştan uzak bir ortamda sükûnet içinde düşünmeye vakti olmuştur[21].
Doktor Vermer, tedavi süresince uygulanacak programı belirleyerek, günde üç öğünlük yeme ve içme listesini kendisine vermişti. Bu esnada doktor; "*tabii beraberinizde un getirdiniz*" diye sormuş, Mustafa Kemal Paşa; "*hayır*" cevabını verince doktor; "*o halde burada ekmek bulamayacaksınız*" karşılığını vermiştir. Doktor ile aralarında geçen bu konuşma savaş nedeniyle bir sağlık merkezinde bile ekmek sıkıntısı yaşandığını göstermekteydi. Konuşmanın devamında Mustafa Kemal Paşa; "*Öyle ise doktor, hemen memleketime döneyim. Bizim memleketimizde yabancılar yerlilerden daha çok yiyip içmektedirler. Ben de hükümetim nezdinde yabancılara ekmek verilmesinin önlenmesini teklif edeyim*", karşılığını verince doktor bizzat un veya ekmek bulmayı üstlenmişti[22].
Notlarından anlaşıldığı üzere yaptığı okumalar arasında şiir, tarih, felsefe, Fransızca romanlar, Almanca kitaplar hatta Marks'ın eleştirileri de bulunuyordu. Anılarında aşağı yukarı her gece yatmadan önce okuduğu kitapları not etmiştir. Fransızca ve Almanca derslerini burada da almaya devam etmesi bu dillere hâkim olma kararlılığının devam ettiğini göstermektedir. O günlere ilişkin bazı notlarını Fransızca yazması ise Fransızcasını ilerlettiğini göstermektedir. Notlarından siyasal ve toplumsal konularla ciddiyetle ilgilendiği anlaşılmaktadır. Orada bulunan Maliye Bakanı Cavit, İttihat ve Terakki üyesi gazeteci Hüseyin Cahit Yalçın, Cemal Paşa'nın eşi ve karşılaştığı diğer Türklerle ülke sorunlarına ilişkin sohbetler etmiştir. Örneğin 9 Temmuz'da Ramazan Bayramı kutlamasına gelen Cemal ve Hüsnü Beylerle şu konuları görüştüklerini yazmaktadır; "*Osmanlı Devleti nasıl bir siyaset izlemelidir? Türklük ülküsü. Arabistan, Türkistan ve öteki uluslar hakkında izlenecek bakış açısı ne olmalıdır? Devlet adamlarımızın ülke hakkındaki bilgileri (Cavit Bey, Maliye Bakanı). Aşar vergisinin alınma usulleri, İsmail Hakkı Paşa sorunu. Cemal Paşa sorunu*". Görüşme konusu olarak not ettiği bu liste Mustafa Kemal Paşa'nın ülkenin iç ve dış sorunlarını değerlendirdiğini, büyük tepkilere yol açan aşarın toplanma yöntemini tartışırken İttihat ve Terakki'nin eğilim gösterdiği Türkçülük-Turancılık konusunu da irdelediği görülmektedir.
Mustafa Kemal Paşa, Karlsbad'da iken kadın haklarına dair gözlemleri daha önceki gözlemleriyle de birleşince Türk kadınının toplum içindeki yeri ve kadın özgürlüğü konusunu ihmal etmediği, geleceğe yönelik planlarının içinde olduğu anlaşılmaktadır. Atatürk'ün 1916 tarihinde 16. Kolordu Komutanı iken tuttuğu notlarda da savaşın ortasında kadın hakları üzerinde önemle durduğu görülmektedir. Çünkü kadının özgürleşmesi ve gelişiminin toplumun gelişimine bağlı olduğu öngörüsüne sahip bir liderdir. Karlsbad'da bir Türk kadınıyla yaptığı sohbette, aşamalı bir ıslahat yaklaşımına karşı çıkarak hızla yapılan bir değişim ihtiyacını yönelik olarak toplumsal devrim konusuna değinmiştir. Mustafa Kemal Paşa, notları tuttuğu dönemde artık başarılı bir komutan, Veliaht ile yaptığı Almanya yolculuğunda başta Alman İmparatoru olmak üzere generaller ve politikacılar ile tanışma ve tartışma olanağına sahip olmuş bir komutandır. Zihninde kendisini bir devlet adamı olarak konumlandırdığında aklında toplumsal bir devrim olduğunu hatıra defterinde tuttuğu notlardan anlamak mümkündür[23]. Dolayısıyla Karlsbad günlerinde notları arasında yer alan önemli kararlardan birisi, yönetme gücünü eline aldığında tasarladığı değişimlere ilişkindir. Yönteme ilişkin kararlarının yer aldığı notlarında Türk kadınının çağdaşlaşmasını, iktidara geldiği zaman bir darbe ile çözeceğini Fransızca "*coup*" kelimesi ile vurgulamış, kendisini de şu cümlelerle öne çıkarmıştır; "*Benim elime büyük yetki ve kudret geçerse, ben sosyal hayatımızda arzu edilen inkılabı bir anda bir "coup" ile tatbik edeceğimi zannederim.*

[20] Karlsbad Hatıraları, s.52.
[21] Şevket Süreyya Aydemir, *Tek Adam*, Remzi Kitabevi, İstanbul 2007, s.281.
[22] Karlsbad Hatıraları, s.42-43.
[23] Emre Kongar, *Devrim Tarihi ve Toplumbilim Açısından Atatürk*, Remzi Kitabevi, İstanbul 2008, s. 177.

Zira ben bazıları gibi halkın anlayışını, önde gelenlerin anlayışlarını yavaş yavaş benim anlayışım ölçüsünde planlarıma ve düşüncelerime alıştırmak suretiyle bu işin yapılabileceğini kabul etmiyor ve böyle harekete karşı ruhum isyan ediyor. Neden ben bu kadar senelik yükseköğrenim gördükten, medeni ve sosyal hayatı inceledikten ve hürriyeti elde etmek için ömrümü ve zamanımı harcadıktan sonra avam (sıradan halkın) seviyesine ineyim? Onları kendi seviyeme çıkarayım, ben onlar gibi değil, onlar benim gibi olsunlar"[24]. Bu sözleri mağrur bir tavırdan ziyade kişisel nitelikleriyle ulusu yüceltecek nitelikleri birleştirerek toplumun gelişmesi gerektiğine yönelik kendisinin de önder rolü üstlendiği bir ruh halinin dışa vurumu olarak yorumlanabilir[25]. Aynı sohbette kadının toplumdaki rolünü de değerlendirmiş, geleneklerin bir parçası olan erdemi göz ardı etmeyerek modern eğitimle toplumdaki yerlerinin düzeltilme ihtiyacına şu cümleleriyle vurgu yapmıştır; "*Bu kadın meselesinde cesur olalım. Vesveseyi bırakalım. Açılsınlar, onların dimağlarını ciddi ilim ve fen ile tezyin edelim. İffeti, fenni sağlık açısından izah edelim*". Görüldüğü üzere Mustafa Kemal Paşa, düşünecek zamanının olduğu bu evrede tamamıyla toplumsal devrim üzerine odaklanmıştır.

5 Temmuz 1918'de Mustafa Kemal Paşa'yı görmeye gelen bir arkadaşı, Sultan Reşat'ın 3 Temmuz tarihinde vefat ettiğini, tahta kardeşi Vahdettin'in geçtiğini haber verince durumu "*teessür ve teessüf ederim*" sözleriyle karşılamış, notlarında üzüntü duymasını şöyle ifade etmiştir; "*kendisiyle başlamış olan münasebeti azami derecede ilerletmek fırsatı elimdeyken gönlü tok davrandım. Bir defadan başka ziyaretine gitmedim. Hatta bu defa İstanbul'dan ayrılırken veda bile etmedim. İşte teessür bundan ileri geliyor*"[26]. Teessüf etmesi ise saltanat değişikliği sırasında İstanbul'da bulunmayışı olabilir. Çünkü saltanat değişikliği ülke için önemli bir olaydı. Birkaç ay önce gerçekleşen Almanya seyahatinde kendisine eşlik ettiği yeni padişaha bir tebrik telgrafı göndermiştir. Ertesi gün günlüğüne şunları yazmıştır; "*Kumandanların en büyük cesareti, sorumluluktan korkmamalarıdır. Hakikaten sorumluluğun ağırlığını ben kendi nefsimde tecrübe ettim. Namuslu ve şeref sahibi bir kumandan için ölüm hiçbir zaman hatıra gelmez, onu düşündüren icraatının isabet ve isabetsizliğidir*". Yeni bir padişah geleceğe dair yeni bir yol çizme ihtimalini ortaya koyuyordu. Karlsbad'da iken Doğu Cephesi'nde beraber bulunmuş olduğu İzzet Paşa'nın padişahın askeri danışmanı ve kurmay başkanı olduğu haberi onun için umut verici olmuştu. Çünkü İzzet Paşa'nın İttihat ve Terakki ile arası iyi değildi, bu atama kendisinin de anlaşmazlık içerisinde olduğu Enver Paşa'nın yetki alanını daraltabilirdi. Amacı Vahdettin ile yeniden bir görüşme gerçekleştirebilmek, kendisini Genelkurmay Başkanlığı'na atanmasını ve orduların yönetimini kendisine bırakmasını istemek olmuştur[27].

6 Temmuz tarihli notlarında akşam yemeği esnasındaki sohbetlerinden bahsederken askerlik konularını da konuştuklarını kendisine yöneltilen bir soru üzerine şu yanıtı verdiğini aktarmıştır; "*Askerlik hayatımda en çok zevk duyuran Muş cephesinde 8 Tümen ile yaptığım geri çekilme manevrasındaki başarı olmuştur….Ordu Kumandanı İzzet Paşa hazretlerinden elen telgraflarda bir bozgun ve felaket mi olduğundan ve bu uğursuz durumdan sonra düşmanın nerelere kadar gelebileceğinden, daha ne kadar kuvvet istediğimden bahsediyordu. Bu telaşta hakkı da yok değildi. Düşmanın beş misli üstün kuvveti karşısında….bir gece manevrasıyla daha geriye ikinci bir hatta çektim. Düşman bizi mağlup ettiğine inandı, daha fazla takip etmedi. Karşımda dağınık üç grup halinde tertibat aldı. On gün sonra Bitlis cephesinde de beraber olmak üzere burada yaptığım taarruzla düşmanı mağlup ve perişan ederek Muş'u zapt ettim. Aynı günde Bitlis'i de zapt etmiştim*"[28]. Mustafa Kemal Paşa, taktiksel olarak başarılı bir biçimde geri çekilme tecrübesini, Birinci Dünya Savaşı'nın sonunda İngiliz taarruzu karşısında Türk ordusunu Halep'in kuzeyine ve Kurtuluş Savaşı esnasında Sakarya Nehri'nin doğusuna çekilmeyle de uygulamıştır.

7 Temmuz tarihli notlarında kendisinin ortama nasıl uyum sağladığına dair bir örnek vermiştir. "*Şimdiye kadar akşam yemekleri için İmperial'e gittikçe ya asker elbisesi ile bulunuyor veya caket atay yahut siyah renkli bir sivil elbise giyiyordum. Halbuki buranın sakinlerinin yıkanma, tıraş olma ve giyinme işleri, erkeklerin smokinli bulunmaları bana da sivil gittiğim zaman smokinimi giymeyi tercih ettirdi*"[29].

[24] Karlsbad Hatıraları, s.66.
[25]Kongar, a.g.e., s.167.
[26] Karlsbad Hatıraları, s.60.
[27] Paraşkev Paruşev, *Demokrat Diktatör Atatürk*, Kent Yayınları, Ankara 2007, s.106.
[28] Karlsbad Hatıraları, s.63.
[29] A.g.e., s.71.

Mustafa Kemal Paşa'nın giyimine ve öz bakımına hayatı boyunca büyük önem verdiği bilinmektedir. Kıyafetin bir insanın hem kendisine hem de çevresine saygısını gösteren bir unsur olması bilinciyle hareket etmiş olan Mustafa Kemal Atatürk'ün ileride yapacağı Kıyafet Kanunu ile çağdaş uygarlık düzeyine ulaşma idealini hedeflediği ve zihniyet değişikliğini sağlamayı amaçladığı söylenebilir.

10 Temmuz tarihli notlarında şöyle diyecektir; "*Bu iki günde neler olduğunu yazmayacağım. Birçok hatıralarım gibi bunların da unutulanlara karışmasında ne kötülük var. Yalnız şu kadar diyelim ki, insanlar hakikati daima gizlerler"*[30]. Hatıra deflerine her şeyi not etmekten imtina eden Mustafa Kemal Paşa'nın bu sözleriyle tedbirli davranmanın gerekliliğini vurguladığı görülmektedir.

Tamamen Fransızca yazılmış 14 Temmuz tarihli notlarında Osmanlı Devleti'nin son yıllardaki savaşları ile ilgili bir değerlendirme yapmıştır. Osmanlı ordusunun Tablusgarp'taki kötü idaresinin Balkan Savaşları felaketinin eski zihniyetin çöküşüne neden olduğunu, savaşların sonuçlarının Türkiye'ye hakim olan şahısların bilgisizliğinden kaynaklandığını ifade ederek sözlerine şöyle devam edecektir; "*Büyük ve hakiki Türk ordusu oluşturulamamıştı. Öyle zamanlar olmuştu ki, milleti orduya çağırmak yerine birlikler terhis edilmiştir. Bütün iktidarı elinde tutan birkaç şahsın bilgisizliği, cesaretle müdafaa edilebilecek kabiliyetteyken ve kabiliyette olan bir orduyu kullanamadan, memleketin en kıymetli kısmını düşmana ikram etti*"[31]. O'na göre ülkenin hakiki bir orduya ihtiyacı vardı. Böylelikle tüm bu düşüncelerini pratiğe dönüştürerek zafere ulaşan bir Türk ordusuna liderliği Kurtuluş Savaşı ile yapacaktı[32]. Hatıralarında bir komutanın cesaretli olmasını aldığı sorumlulukla bağdaştıran bir yorumda bulunmuş, komutanların en büyük zaaflarını geri çekilme konusunda zamanında karar verememeleriyle örneklemiştir.

Mustafa Kemal Paşa'nın 19 Temmuz tarihinde Başmabeyinci Lütfi Simavi Bey'e yeni görevi olan başmabeyinciliğini kutlamak adına gönderdiği mektuptaki şu cümleler O'nun duygularını ve geleceğe dair beklentilerini anlamak adına önemlidir; "*Efendimizin tahta çıkmaları, bendenizde vatanımızın ve milletimizin saadet ve selameti bakımından fevkalade ümitler uyandırdı. Sultan merhumun (Sultan Reşat) ebedi kaybından üzüntü duymakla beraber, vatanın, milletin, ordunun oyuncak olmaktan kurtulacağı kanaati bu üzüntüyü ortadan kaldırmıştır*"[33]. Mustafa Kemal Paşa kendi tasarıları için yeni padişaha yakın durmayı planlamıştı. Ancak İstanbul'a dönüşünde Vahdettin ile yaptığı görüşmelerde bu ümidi gerçekleşmeyecektir[34]. Rahatsızlığı henüz tam geçmemiş olmasına rağmen Padişahın ölümünden birkaç gün sonra yaveri Cevat Abbas (Gürer)'tan hemen İstanbul'a dönmesini tavsiye eden telgrafı üzerine Mustafa Kemal Paşa tedavisinin devam etmesi nedeniyle önemli bir sebep olmadıkça dönmeyeceğini bildirse de yaverinden ikinci bir telgraf alınca 27 Temmuz 1918 tarihinde Karlsbad'dan ayrılarak Viyana'ya geçmiştir. 27 Temmuz gecesi Viyana'da kaldığı otelde son tuttuğu notlarda şöyle diyecektir; "*Karlsbad'da geçen günlerimin hatıralarını tamamen ve olduğu gibi bu defterlere geçiremedim. Bunun iki sebebi var. Birincisi, lüzumu kadar yazı yazmak için vaktim olmadı. İkincisi, her düşündüğümü her yaptığımı yani bütün fikirlerimi ve hayatımla ilgili sırları bu defterlere nasıl emanet edebilirdim?...Karlsbad'da ettiğim istifade beklenen derecede değildir. Rahatsızlıklarımın belirtileri henüz mevcuttur"*[35]. Bu sözler geleceğe dair büyük planları olan bir liderin temkinli hareket ettiğini göstermekteydi.

Hatıra defterinde yer alan son not ise, "Viyana, 28 Temmuz 1918, Pazar" başlığı altında şöyle sona ermektedir; "*saat 7.30'da uyandım. Üzerimde adeta rahatsızlık derecesinde bir kırgınlık var. Kendimi üşütmüşüm gibi öksürüyorum…Karlsbad'da geçen günlerimin hatıralarını beşinci defterin sonunda kapadım. Şimdi Viyana'ya geçecek bu birkaç günlük hatıra için yeni bir defter, bu defteri açıyorum. Viyana'da Otel Bristol'de geçen dün gece yeni aldığım Fransızca kitaplardan birine başlamak istedim. Hemen hepsinin başından birkaç sayfa okudum fakat devam için hiçbiri üzerinde karar veremedim…Hep gözde geçirdim*"[36].

[30] Karlsbad Hatıraları, s.85.
[31] Karlsbad Hatıraları, s.91.
[32] Gawrch, a.g.e., s.88.
[33] Atatürk'ün Bütün Eserleri, s.205.
[34] Andrew Mango, *Sultan'dan Atatürk'e Türkiye*, Pegasus Yayınları, İstanbul 2009, s.33.
[35] Karlsbad Hatıraları, s.95.
[36] Karlsbad Hatıraları, s.96.

Ancak burada Avrupa'yı kasıp kavuran İspanyol gribine yakalanınca gidişi gecikmiştir[37]. Böylelikle ancak 4 Ağustos tarihinde İstanbul'a ulaşabilmiştir. İstasyondan kendisini karşılayan yaverinden asıl çağıran kişinin padişahın yeni başyaveri Mareşal Ahmet İzzet Paşa olduğunu öğrenir. Padişahla temasın faydalı olacağı görüşündedir. Vahdettin ile ilk görüşmede şu görüşlerini ifade etmiştir; "*Kendiniz başkomutan olun ve kendinize bir vekil değil bir kurmay başkanı seçin, çünkü her şeyden önce yurtta başlıca kuvvet kaynağı olan orduyu doğrudan doğruya ele almak gerekir*"[38]. Vahdettin ile birkaç kez daha görüşme gerçekleştiren Mustafa Kemal Paşa taleplerini dile getirmesine rağmen herhangi bir olumlu yanıt alamadan görüşmeler sonlanmıştır. Mustafa Kemal Paşa'nın Suriye Cephesine ataması o günlerde gerçekleşmiştir[39].

Filistin'deki 7. Ordu Kumandanlığı'na atanması üzerine 1 Eylül 1918 tarihinde Yıldırım Ordu Grubu'na katılmak üzere Nablus'a ulaşmıştı. Ancak gelişinden üç hafta sonra Filistin'de büyük bir İngiliz taarruzu başlamış, orduyu Halep'in kuzeyine çekmek durumunda kalmıştır. Mustafa Kemal Paşa, Birinci Dünya Savaşı'nın sonunda imzalanan Mondros Mütarekesi ile Adana'ya çağrılarak 31 Ekim 1918 tarihinde Yıldırım Orduları Grup Kumandanlığı'nı devralmıştır. Savaş bitmiş görünüyordu ancak teslimiyetçi zihniyetin aksine vatansever bir kadronun öncülüğünde milletin vereceği topyekûn mücadele ile yeni bir evreye geçiyordu. Asıl mücadele Mustafa Kemal Paşa'nın önderliğinde, halkın "*ya istiklal ya ölüm*" ideali etrafında kenetlendiği, Türk milletinin kaderini belirleyecek Kurtuluş Savaşı ile verilecekti.

Sonuç

Mustafa Kemal Atatürk'ün okuma alışkanlığı onun düşünce dünyasının gelişimine büyük katkı sağladığı gibi bu birikimini yazım alanına da yansıtmasını mümkün kılmıştır. O'nun geride bıraktığı eserlerden birisi de Karlsbad'da tedavi olurken tuttuğu günlüktür. 30 Haziran 1918 ile 28 Temmuz 1918 tarihleri arasında tuttuğu günlüğü sayesinde kendisi hakkında doğrudan bilgi almak, kişiliğine dair bir analiz yapmak ve o dönemdeki düşüncelerini öğrenmek mümkün olmuştur. Günlüğünde tedavisinin yanı sıra okuduğu kitapları, görüştüğü insanlarla yaptığı sohbetlerinin içeriği, ülkenin askeri, siyasal, sosyal sorunlarına ve geleceğine dair düşünceleri yer almaktadır.

Hatıratından her koşulda kitap okuduğu hem Fransızcasını hem de Almancasını ilerletmek için özel bir çaba harcadığı anlaşılmaktadır. Günlük eski harflerle tutulmuş olmasına rağmen bazı sayfaları Fransızca, yabancı isimler Latin harflerle yazılmıştır. Karlsbad'da bulunduğu sırada çekilmiş bir fotoğrafta takım elbise giydiği, elinde fötr şapka tuttuğu görülmektedir. Notlarında da ortama uyum sağlayarak akşam yemeklerine smokinle katıldığını belirtmektedir. Orta halli bir aileden gelmiş olmasına rağmen, nerede nasıl davranması gerektiğini bilen, bulunduğu yere uyum sağlayan, dış görünüşüne son derece önem veren bir kişiliğe sahip olduğu anlaşılmaktadır. İleride yapacağı Kıyafet Kanunu için bu dönemdeki gözlemlerinin ve tecrübelerinin bir zemin oluşturduğu söylenebilir. Odasına koymak üzere birkaç buket çiçek aldığına dair notları sayesinde ince bir kişiliğe sahip olduğu anlaşılmakta yıllar sonra çınar ağacının dallarının kesilmemesi için Yalova Köşkü'nün altına ray döşenerek ileri aldırma kararı çevreye olan duyarlılığını gösteren bir diğer örnektir.

Atatürk'ün 1916 tarihinde 16. Kolordu Komutanı iken tuttuğu notlarında kadın hakları üzerinde önemle durduğu gibi Karlsbad'da tuttuğu notlarında da kadın-erkek birlikteliğine ilişkin gözlemleri yer almakta, kadının toplumdaki konumuna ve özgürlüğüne dair geleceğe yönelik planlarının olduğu anlaşılmaktadır. Türk kadının haklarına yönelik tüm bu planlar cumhuriyet döneminde gerçeğe dönüşebilecektir. Notlarında dikkati çeken diğer bir konu, yönetme gücünü eline alması durumunda uygulayacağı yönteme ilişkin kararlılığıdır. Türk kadınının çağdaşlaşmasını iktidara geldiği zaman bir darbe ile çözeceğini ifade etmesi, ileride gerçekleştireceği devrimlerin iz düşümlerine yönelik fikri alt yapısını göstermektedir. Karlsbad Hatıraları, Kurtuluş Savaşı'nın önderi ve Türkiye Cumhuriyeti'nin kurucusu Gazi Mustafa Kemal Atatürk'ün düşünce dünyasının iz düşümlerini analiz etme fırsatı sunduğu gibi tarih yapanın bizzat kaleme aldığı notlar olduğu için de oldukça önemli bir hatırattır.

[37] Kinross, a.g.e., s.147.
[38] Yusuf Hikmet Bayur, *Atatürk Hayatı ve Eseri, Atatürk Araştırma Merkezi Yayınları*, Ankara 1997, s.152.
[39] Aydemir, a.g.e., s.284.

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ATATÜRK'ÜN SOLİDARİST ANLAYIŞININ MİLLET MEKTEPLERİNE YANSIMALARI

REFLECTIONS OF ATATÜRK'S SOLIDARIST THOUGHT ON THE NATION SCHOOLS (MILLET MEKTEPLERI)

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ÖZET

Cumhuriyet'in kuruluş sürecinde gerçekleştirilen eğitim reformları, yalnızca eğitim sisteminin yeniden yapılandırılmasını değil, aynı zamanda yeni devletin toplumsal ve siyasal temellerinin güçlendirilmesini amaçlamıştır. Bu reformların önemli kurumlarından biri olan Millet Mektepleri, Harf İnkılabı sonrasında okuma yazma öğretiminin yaygınlaştırılmasının yanında Cumhuriyet'in temel değerlerini topluma kazandırmayı hedefleyen bir halk eğitimi kurumu olarak faaliyet göstermiştir. Bu yönüyle Millet Mektepleri, Atatürk'ün toplumsal dayanışma, ortak sorumluluk ve millî birlik anlayışının eğitim alanındaki önemli uygulamalarından biri olarak değerlendirilebilir.

Bu çalışmanın amacı, Atatürk'ün solidarist anlayışının Millet Mekteplerine hangi yönleriyle yansıdığını ortaya koymaktır. Araştırmada nitel araştırma yöntemi benimsenmiş, doküman incelemesi tekniğinden yararlanılmıştır. Çalışmanın temel veri kaynaklarını Atatürk'ün söylev ve demeçleri, *Medeni Bilgiler* notları, Millet Mektepleri Talimatnamesi, dönemin resmî belgeleri, Türkiye Büyük Millet Meclisi tutanakları ile konuya ilişkin bilimsel literatür oluşturmaktadır.

Araştırmada öncelikle solidarizm kavramı ve Atatürk'ün bu düşünceyi nasıl yorumladığı ele alınmış; ardından Millet Mekteplerinin kuruluş amacı, işlevi ve eğitim anlayışı incelenmiştir. Daha sonra Millet Mektepleri; eğitimde fırsat eşitliği, toplumsal dayanışmanın güçlendirilmesi, ortak vatandaşlık bilincinin geliştirilmesi, millî birlik ve bütünleşmenin desteklenmesi ile devlet ve toplumun eğitim sorumluluğunu paylaşması açısından değerlendirilmiştir.

Araştırma sonucunda Millet Mekteplerinin yalnızca yeni Türk alfabesinin öğretilmesini amaçlayan yaygın eğitim kurumları olmadığı, aynı zamanda Cumhuriyet'in toplumsal bütünleşme hedefini destekleyen ve vatandaşlar arasında ortak aidiyet duygusunu güçlendiren kurumsal bir işlev üstlendiği sonucuna ulaşılmıştır. Bu bağlamda Millet Mekteplerinin, Atatürk'ün halkçılık ilkesiyle uyumlu solidarist toplum anlayışının eğitim alanındaki en önemli yansımalarından biri olduğu değerlendirilmektedir. Çalışmanın, Atatürk dönemi eğitim politikalarının düşünsel temellerinin anlaşılmasına katkı sağlaması ve Cumhuriyet eğitim tarihine farklı bir bakış açısı sunması beklenmektedir.

Anahtar Kelimeler: Atatürk, solidarizm, Millet Mektepleri, halkçılık, eğitim tarihi, Cumhuriyet dönemi.

ABSTRACT

The educational reforms implemented during the establishment of the Republic of Türkiye aimed not only to restructure the educational system but also to strengthen the social and political foundations of the new state. Among the most significant institutions established during this period were the Nation Schools (Millet Mektepleri), which were founded following the Alphabet Reform to disseminate the new Turkish alphabet among the wider population. Beyond promoting literacy, these institutions played a crucial role in fostering the fundamental principles and values of the Republic. In this respect, the Nation Schools may be regarded as one of the institutional reflections of Atatürk's understanding of social solidarity, collective responsibility, and national unity in the field of education.

The aim of this study is to examine how Atatürk's solidarist thought was reflected in the Nation Schools. The study adopts a qualitative research design and employs document analysis as its primary research method. The main sources include Atatürk's speeches and statements, his *Civic Knowledge (Medeni Bilgiler)* notes, the Nation Schools Directive, official documents of the period, the *Proceedings of the Grand National Assembly of Türkiye*, and the relevant scholarly literature.

The study first examines the concept of solidarism and Atatürk's interpretation of this intellectual tradition. It then analyzes the aims, organizational structure, and educational philosophy of the Nation Schools. Finally, the Nation Schools are evaluated in terms of promoting equality of educational opportunity, strengthening social solidarity, fostering a shared sense of citizenship, reinforcing national unity and social cohesion, and encouraging the shared responsibility of the state and society in education. The findings indicate that the Nation Schools were not merely institutions established to teach the new Turkish alphabet; rather, they functioned as important educational institutions that supported the Republic's objective of social integration, strengthened a shared sense of citizenship, and brought together different segments of society around common national values. Accordingly, the study concludes that the Nation Schools constituted one of the most significant institutional manifestations of Atatürk's solidarist understanding of society, closely associated with the principle of populism (*Halkçılık*). It is expected that this study will contribute to a better understanding of the intellectual foundations of educational policies in the early Republican period and offer a new perspective on Atatürk's educational thought through the lens of solidarism.

Keywords: Atatürk; solidarism; Nation Schools (Millet Mektepleri); populism (*Halkçılık*); history of education; Early Republican period.

ANDRÉ KERTÉSZ'İN ESZTERGOM (1915) VE BUDAPEST (1971) FOTOĞRAFLARINDA OKUMANIN TEMSİLİ

THE REPRESENTATION OF READING IN ANDRÉ KERTÉSZ'S ESZTERGOM (1915) AND BUDAPEST (1971)

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Özet
Bu çalışma, André Kertész'in *On Reading* seçkisi kapsamında Macaristan'da çektiği *Esztergom, Hungary (Three Boys Reading)* (1915) (Görsel 1) ve *Budapest (Large Statue and Woman Reading on Stool)* (1971) (Görsel 2) adlı iki fotoğrafta okuma eyleminin farklı tarihsel ve toplumsal koşullar içerisinde nasıl temsil edildiğini incelemektedir. Aralarında elli altı yıllık bir zaman farkı bulunan bu iki fotoğraf, aynı proje ve coğrafi bağlam içerisinde üretilmiş olmalarına karşın okuma eylemini farklı özne-mekân ilişkileri üzerinden göstermeleri nedeniyle amaçlı örnekleme yöntemlerinden maksimum çeşitlilik örneklemesi doğrultusunda seçilmiştir. Nitel araştırma yaklaşımı çerçevesinde gerçekleştirilen çözümlemede kompozisyon, figürlerin kadraj içerisindeki konumu, bedenler arasındaki fiziksel ilişki, bakış yönleri ve perspektif değerlendirilmiş; elde edilen bulgular dönemin toplumsal ve tarihsel koşullarıyla birlikte yorumlanmıştır. Bulgular, *Esztergom, Hungary (Three Boys Reading)* (1915) (Görsel 1) adlı fotoğrafta üç çocuğun tek bir kitap etrafında kurduğu fiziksel yakınlığın okumayı paylaşılan bir deneyim olarak görünür kıldığını; çıplak ayaklar, yırtık giysi ve ortak kitap kullanımının ise dönemin yoksulluk koşullarıyla birlikte değerlendirildiğinde dayanışma kavramını öne çıkardığını göstermektedir. *Budapest (Large Statue and Woman Reading on Stool)* (1971) (Görsel 2) adlı fotoğrafta ise kamusal kent mekânında tek başına okuyan kadın figürü, okumanın bireysel niteliğinin yanı sıra kadınların kamusal yaşamdaki artan görünürlüğü bağlamında değerlendirilmiştir. İki fotoğrafın karşılaştırılması, Kertész'in aynı gündelik eylemi farklı dönemlerde beden, nesne ve mekân arasındaki değişen ilişkiler aracılığıyla farklı toplumsal anlamlara açtığını; okuma eyleminin bir fotoğrafta yoksulluk ve dayanışma, diğerinde ise bireysellik ve kamusal görünürlük ekseninde farklılaştığını ortaya koymaktadır.
Anahtar Kelimeler: André Kertész, *On Reading*, fotoğraf, okuma, görsel analiz, özne-mekân ilişkisi.

Abstract
This study examines how the act of reading is represented under different historical and social conditions in two photographs taken by André Kertész in Hungary as part of his On Reading series: Esztergom, Hungary (Three Boys Reading) (1915) (Figure 1) and Budapest (Large Statue and Woman Reading on Stool) (1971) (Figure 2). Separated by fifty-six years, the two photographs were selected through maximum variation sampling, a purposive sampling strategy, because they were produced within the same project and geographical context while representing the act of reading through different subject–space relationships. Within a qualitative research framework, the analysis focused on composition, the positioning of figures within the frame, physical relationships between bodies, directions of gaze, and perspective; the findings were then interpreted in relation to the social and historical conditions of the respective periods. The findings indicate that in Esztergom, Hungary (Three Boys Reading) (1915) (Figure 1), the physical proximity of three boys gathered around a single book renders reading as a shared experience, while their bare feet, torn clothing, and collective use of the book, when considered in relation to the poverty of the period, foreground the notion of solidarity. In Budapest (Large Statue and Woman Reading on Stool) (1971) (Figure 2), the solitary female figure reading in an urban public space is interpreted in relation to both the individual character of reading and the increasing visibility of women in public life. The comparison of the two photographs demonstrates how Kertész opens the same everyday act to different social meanings through changing relationships between body, object, and space across different periods. While reading is associated with poverty and solidarity in the first photograph, it is framed through individuality and women's public visibility in the second.
Keywords: André Kertész, *On Reading*, photography, reading, visual analysis, subject–space relationship.

1. Giriş

20. yüzyıl fotoğrafının önemli isimlerinden biri olan André Kertész (1894–1985), gündelik yaşamın sıradan anlarını kendine has bir tarzda yansıtan fotoğrafik yaklaşımıyla tanınmaktadır. Foto-muhabirliğin öncü isimlerinden biri olarak değerlendirilen Kertész, belgesel nitelikli çalışmalarının yanı sıra Dada akımının etkilerini taşıyan deneysel fotoğraflarıyla da 20. yüzyıl fotoğrafının etkili isimleri arasında kabul edilmektedir (İstanbul Modern, t.y.). İlk kamerasını 1912 yılında edinen Kertész, erken dönem çalışmalarında ailesini, yakın çevresini, Macaristan kırsalını ve gündelik yaşamdan sahneleri fotoğraflamaya başlamıştır (Holden Luntz Gallery, t.y.). Macaristan'da başlayan bu fotoğrafik üslubunu daha sonra Paris ve New York'ta sürdüren Kertész'in çalışmalarında kent yaşamı, insanlar arasındaki ilişkiler, gündelik yaşam ve çoğu zaman gözden kaçan sıradan anlar önemli bir yer tutmaktadır. Örneğin Szarkowski, Kertész'in fotoğrafik üslubunun temel özelliklerinden birini "sıradan olanın önemini gören bir bakış" olarak tanımlamaktadır (Szarkowski 1964, s. 4). Kertész'in bu tutumu, farklı dönemlerde ve coğrafyalarda kitap, gazete ya da çeşitli basılı materyalleri okuyan insanları konu alan *On Reading* projesinde de net biçimde görülmektedir. 1915'ten itibaren farklı zamanlarda gerçekleştirilen fotoğraflardan oluşan proje, çocuklardan yetişkinlere farklı yaş gruplarındaki insanları sokak, park, kütüphane, toplu taşıma araçları, balkonlar ve farklı kamusal ya da özel mekânlarda okurken göstermektedir. Bu fotoğrafların önemli bir bölümü 1971 yılında yayımlanan *On Reading* adlı kitapta bir araya getirilmiştir (Kertész, 1971). Çalışmanın farklı dönemlerden örnekleri, okuma eyleminin farklı coğrafi ve toplumsal koşullar içindeki sürekliliğini gösterirken, okuyan bireyin çevresindeki mekânla ve diğer insanlarla kurduğu ilişkinin değişkenliğini de göstermektedir. Bu açıdan bakıldığında projedeki fotoğraflar okuma eyleminin farklı zaman ve mekânlarda nasıl dönüştüğünü gösteren belgeler olarak da değerlendirilebilir.

Bu çalışma, On Reading kapsamında Macaristan'da çekilmiş *Esztergom, Hungary (Three Boys Reading)* (1915) (Görsel 1) ve *Budapest (Large Statue and Woman Reading on Stool)* (1971) (Görsel 2) adlı iki fotoğrafa odaklanmaktadır. Aralarında elli altı yıllık bir zaman farkı bulunan bu iki fotoğrafta okuma eylemi, farklı özne ve mekân ilişkileri içerisinde temsil edilmektedir. *Esztergom, Hungary (Three Boys Reading)* (1915) (Görsel 1) fotoğrafında üç çocuk aynı okuma eylemini paylaşırken, *Budapest (Large Statue and Woman Reading on Stool)* (1971) (Görsel 2) fotoğrafında tek başına okuyan bir kadın kamusal kent mekânı içerisinde görüntülenmektedir. Bu farklılık, öznenin diğer insanlarla, çevresiyle ve mekânla kurduğu ilişkiye dair önemli ipuçları sunmaktadır.

Çalışmanın temel problemi, okuma eyleminin bu iki fotoğrafta özne ve mekân arasındaki ilişki üzerinden nasıl farklı biçimlerde temsil edildiğidir. Bu doğrultuda çalışmanın temel araştırma sorusu şu şekilde belirlenmiştir: Kertész'in 1915 ve 1971 yıllarında Macaristan'da çektiği bu iki fotoğrafta okuma eylemi, değişen özne ve mekân ilişkileri aracılığıyla nasıl farklı biçimlerde açığa çıkmaktadır?

Bu çalışma, André Kertész'in iki fotoğrafının karşılaştırmalı olarak incelenmesine dayanan nitel bir araştırmadır. Fotoğrafların biçimsel ve içeriksel çözümlemesinde Gillian Rose'un (2016, s. 56) "kompozisyonel yorumlama" yaklaşımından yararlanılmıştır. Rose (2016, s. 56), bu yaklaşımı "bir imgenin görünüşünü ifade etmek için ayrıntılı bir söz dağarcığı sunan" bir yöntem olarak ele almakta ve "kompozisyonel yorumlama" kavramını, özellikle Batı güzel sanatlar geleneğindeki resim sanatıyla ilişkili olarak gelişen belirli sanat tarihi yaklaşımlarını tanımlamak üzere kullandığını belirtmektedir. Bu doğrultuda fotoğraflar; kompozisyon, figürlerin kadraj içerisindeki konumu, bedenler arasındaki fiziksel ilişki, bakış yönleri ve perspektif kullanımı açısından incelenmiştir. Elde edilen bulguların düzenlenmesi ve yorumlanmasında ise Yıldırım ve Şimşek'in (2018, s. 239) "betimsel analiz" yaklaşımından yararlanılmıştır. Araştırmanın örneklemini *Esztergom, Hungary (Three Boys Reading)* (1915) (Görsel 1) ve *Budapest (Large Statue and Woman Reading on Stool)* (1971) (Görsel 2) adlı fotoğraflar oluşturmaktadır. Söz konusu fotoğraflar, *On Reading* projesi içerisinde Macaristan'da üretilmiş olmaları ortaklığının yanı sıra, aralarında elli altı yıllık bir zaman farkının bulunması ve okuma eylemini farklı özne-mekân ilişkileri içerisinde göstermeleri nedeniyle amaçlı örnekleme yöntemlerinden maksimum çeşitlilik örneklemesi doğrultusunda seçilmiştir (Yıldırım & Şimşek, 2018, ss. 119–120). Böylece aynı proje ve coğrafi bağlam içerisinde farklı dönemlere ve özne-mekân ilişkilerine sahip iki fotoğrafın karşılaştırılması amaçlanmıştır. Analiz sürecinde öncelikle her iki fotoğraf ayrı ayrı ele alınarak fotoğrafik açıdan çözümlenmiş, bu özelliklerin fotoğrafların anlamı üzerindeki etkileri yorumlanmıştır. Ardından "Karşılaştırmalı Analiz ve Tartışma" bölümünde iki fotoğraftan elde edilen bulgular özne, nesne ve mekân ilişkileri üzerinden karşılaştırılmıştır.

Ayrıca bu bölümde yoksulluk, dayanışma, bireysellik ve kamusal görünürlük gibi öne çıkan kavramlar, fotoğrafların üretildiği dönemlere ilişkin Macaristan merkezli tarihsel kaynaklarla birlikte yorumlanmıştır.

Görsel 1 :André Kertész, Esztergom, Hungary (Three Boys Reading), 1915, Esztergom, Macaristan



3. Esztergom, Hungary (Three Boys Reading) (1915) (Görsel 1)

André Kertész'in 1915 yılında Macaristan'ın Esztergom kentinde çektiği *Esztergom, Hungary (Three Boys Reading)* (1915) (Görsel 1) adlı fotoğrafa bakıldığında yan yana oturmuş üç erkek çocuğu görülmektedir. Fotoğrafın merkezinde yer alan çocuk elindeki kitabı tutarken diğer iki çocuk da başlarını kitaba doğru eğmiş biçimde aynı metne odaklanmaktadır. Çocuklardan hiçbirinin kameraya bakmaması, fotoğrafın kurgulanmadığı izlenimi vermekte ve fotoğrafçının varlığını ikinci plana itmektedir. Fotoğrafta ilk bakışta göze çarpan noktalardan biri, üç çocuğun birbirlerine oldukça yakın konumlanmış olmalarıdır. Çocukların omuzlarının birbirine değecek kadar yaklaşması ve üç figürün de aynı noktaya yönelmesi, birbirlerinden bağımsız üç ayrı kişiden ziyade tek bir eylem etrafında birleşmiş tek bir beden izlenimi yaratmaktadır. Üç figürün baş ve omuzlarının birbirine yakın olarak konumlanması, kadrajın merkezinde oldukça yoğun bir dağılım olduğunu göstermektedir. Çocukların bakışlarının farklı yönlere dağılmak yerine aynı noktada birleşmesi ise gözün de doğrudan kitabın bulunduğu alana yönelmesine aracılık etmektedir. Bu bakımdan fotoğrafın biçimsel tarafının da çocuklar arasındaki birlikteliği desteklediği söylenebilir.

Fotoğrafın arka planında oldukça sade bir duvar, ön planında ise çocukların oturduğu doğal bir zemin bulunmaktadır. Kadraj içinde çocukların dışında dikkat dağıtacak herhangi bir nesnenin bulunmaması, gözün doğrudan figürlere ve onların gerçekleştirdiği okuma eylemine yönelmesini sağlayan diğer unsur olarak öne çıkmaktadır. Çocukların kıyafetleri, şapkaları ve oturma biçimleri de fotoğrafın gündelik yaşamın bir yansıması olduğu izlenimi vermektedir. Bu durum Kertész'in gündelik yaşam içerisinde çoğu zaman gözden kaçabilecek küçük anlara yönelttiği bakışla da tutarlılık göstermektedir.

Fotoğraftaki okuma eylemini dikkat çekici hale getiren önemli unsurlardan bir diğeri de üç çocuğun da aynı kitaba yönelmesidir. Bu durum, fotoğrafta okumanın bireysel bir uğraştan ziyade paylaşılan bir eylem olarak algılanmasını sağlamaktadır. Çocuklardan birinin kitabı tutması, diğer ikisinin ise ona doğru yaklaşması, kitabı çocuklar arasındaki fiziksel yakınlığı oluşturan noktalardan biri haline getirmektedir. Bu bağlamda Kertész'in okuma eylemini çocuklar arasındaki yakınlığı sembolize eden bir deneyim ve aynı zamanda olası bir dayanışma biçimi olarak fotoğrafladığı da söylenebilir. Üç çocuktan ikisinin çıplak ayaklı ve çocuklardan birinin pantolonunda yırtık olması, figürlerin yoksulluk içerisinde yaşadıklarını düşündüren göstergeler olarak değerlendirilebilir. Kitabın üç çocuk tarafından paylaşılması ise bu koşullar içerisinde ortaklaşa gerçekleştirilen okuma eyleminin ve dayanışmanın bir sembolü olarak yorumlanabilir. Bu anlamda fotoğrafta okuma, bireylerin metinle kurduğu ilişkinin yanı sıra, paylaşımı ve yakınlığı mümkün kılan gündelik bir eylem olarak da değerlendirilebilir.

Görsel 2 : André Kertész, Budapest (Large Statue and Woman Reading on Stool), 1971, Budapeşte, Macaristan



4. Budapest (Large Statue and Woman Reading on Stool) (1971) (Görsel 2)

André Kertész'in 1971 yılında Budapeşte'de çektiği *Budapest (Large Statue and Woman Reading on Stool)* (1971) (Görsel 2) adlı fotoğrafa bakıldığında, kamusal bir mekânda büyük ölçekli bir heykelin yakınında tek başına okuyan bir kadın görülmektedir. Kadının küçük bir tabure üzerinde oturması ve önündeki bankı masa gibi kullanarak metinlere yönelmesi, gündelik bir okuma anının modern kamusal mekâna yansımaları olarak değerlendirilebilir. Heykelin kadraj içerisindeki kütlesel ağırlığı ve kadın figürünün küçük ölçekte kalması, fotoğraftaki perspektifin etkisini göstermektedir. Böylelikle göz bir taraftan heykele kayarken diğer taraftan gündelik eylemini sürdüren kadın figürüne yönelmektedir.

Fotoğrafta bireyselliği çağrıştıran diğer unsurlar ise kadının dış görünüşünde de aranabilir. Kadın figürünün mini elbisesi, açık ve topuklu ayakkabıları ile kısa saçları, dönemin kentli, modern kadın imgesiyle kolayca ilişkilendirilmesine olanak sağlamaktadır. Bu göstergeler, kadının kamusal alan içerisindeki tekil varlığını güçlendiren ayrıntılar olarak yorumlanabilir.

Fotoğrafta dikkat çeken bir diğer unsur, kadının çevresindeki kamusal mekândan adeta soyutlanmış biçimde okumayı sürdürmesidir. Yani, okuma eylemi, kamusal bir alan içerisinde gerçekleşmesine rağmen kadının tek başına gerçekleştirdiği kişisel bir eylem gibi görünmektedir. Museum of Contemporary Photography'in sergiye ilişkin tanıtım yazısında, Kertész'in *On Reading* serisinde kamusal ve özel yaşamın şiirselliğine odaklandığı ve "okumanın kişiyi içine çeken niteliğini evrensel bir haz olarak ele aldığı" belirtilmektedir (Museum of Contemporary Photography, t.y.). Bu bağlamda *Budapest (Large Statue and Woman Reading on Stool)* (1971) (Görsel 2) fotoğrafında okuma eylemi, kişinin fiziksel olarak kamusal alan içerisinde bulunmasına rağmen çevresiyle arasına görünmez bir mesafe koymasına aracılık eden, haz verici bir eylem gibi görünmektedir.

Heykel ile kadın figür arasındaki perspektif ilişkisi, görüntünün bağlamsal olarak yorumlanmasını da mümkün kılmaktadır. Bu bağlamda heykelin, kamusal mekânın kalıcı ve anıtsal bir parçası olarak kadrajda güçlü bir alan kapladığı, okuyan kadının ise gündelik yaşamın geçici ancak -Kertészci anlamda- özel bir anını temsil ettiği iddia edilebilir. Aynı zamanda Kertész'in bu kadrajda, durağan ve kalıcı olan heykel ile yaşamın içerisinde sıradan bir eylemi sürdüren kadının geçiciliğini aynı kadraj içerisinde karşı karşıya getirdiği de söylenebilir.

5. Karşılaştırmalı Analiz ve Tartışma

Kertész'in elli altı yıl arayla Macaristan'da çektiği iki fotoğraf birlikte değerlendirildiğinde, ilk dikkat çeken farklılık okuma eyleminin figürler arasında nasıl değişkenlik gösterdiğidir. *Esztergom, Hungary (Three Boys Reading)* (1915) (Görsel 1) fotoğrafında üç çocuğun bedenleri aynı kitap etrafında birbirine yaklaşmakta, başların yönü ve bakışlar kadrajın merkezindeki ortak noktada birleşmektedir.

Budapest (Large Statue and Woman Reading on Stool) (1971) (Görsel 2) fotoğrafında ise okuma tek bir figür üzerinden kurulmaktadır. Burada kadının bedeni başka bir bedenden ziyade içinde bulunduğu geniş kamusal mekânla ilişki içerisindedir. Dolayısıyla iki görüntü arasındaki temel karşıtlıklardan birinin bireysellik ve birliktelik kapsamında olduğu söylenebilir.

Fotoğraflardaki bir diğer farklılık ise okunan metinlerin işlevi kapsamındadır. *Esztergom, Hungary (Three Boys Reading)* (1915) (Görsel 1) adlı fotoğrafta tek bir kitabın üç kişi tarafından paylaşılması, kitabı yalnızca okunacak bir materyal olmaktan çıkarmakta ve figürleri birbirine bağlayan güçlü bir dayanışma ve ortaklığa işaret etmektedir. Kitap ortadan kaldırıldığında çocukların bedenlerini birbirlerine doğru yönelten temel neden de ortadan kalkacak gibidir. Bu nedenle kitap, kompozisyonu bir arada tutan temel unsurlardan biri olarak da değerlendirilebilir. Manguel, *Okumanın Tarihi* adlı eserinin *Sessiz Okurlar* başlıklı bölümünde, yüksek sesle gerçekleştirilen okumanın aynı mekânda bulunan kişiler açısından bir "ortaklaşa okuma" anlamına geldiğini belirtmektedir (Manguel, 1996, s. 50). *Esztergom, Hungary (Three Boys Reading)* (1915) (Görsel 1) fotoğrafında kitabın sesli okunduğuna dair bir detay yoktur; ancak Kertész'in fotoğrafındaki çocukların fiziksel olarak da olsa bir "ortaklaşa okuma" eylemini deneyimledikleri söylenebilir.

Budapest (Large Statue and Woman Reading on Stool) (1971) (Görsel 2) fotoğrafında ise metinle kurulan ilişki tümüyle farklıdır. Kadının dikkatini çevresindeki büyük ölçekli heykelden uzaklaştırarak önündeki metinlere yöneltmesi, okuma eyleminin kamusal mekân içerisinde kişisel bir alan oluşturma biçimini öne çıkarmaktadır. Fotoğrafta yer alan bank ve heykel, buranın kamuya açık bir park ya da benzeri bir alan olabileceğini düşündürmektedir. Kadrajda başka insanlar görünmese de mekânın niteliği çevrede başka kişilerin de bulunabileceği ihtimaline işaret etmektedir. Italo Calvino, *Bir Kış Gecesi Eğer Bir Yolcu* adlı metninde, "iki kişi bir arada olunduğunda bile insanın yalnız başına okuduğunu" belirtmektedir (2008, s. 148). Bu ifade, *Kertész'in Budapest (Large Statue and Woman Reading on Stool)* (1971) (Görsel 2) fotoğrafındaki okuma eyleminin bireysel niteliğini düşünmek açısından önemli bir referans sunmaktadır.

İki fotoğraf arasındaki diğer bir fark, figürlerin kadraj içerisindeki ölçekleri üzerinden de belirginleşmektedir. *Esztergom, Hungary (Three Boys Reading)* (1915) (Görsel 1) fotoğrafında çocukların birbirine yakın konumlanması kadraj içerisinde sıkışık ve kapalı bir alan yaratırken, arka plandaki sade yüzey figürlerin önüne geçmemektedir. Gözün hareketi çocukların başları ile kitap arasında dolaşmaktadır. *Budapest (Large Statue and Woman Reading on Stool)* (1971) (Görsel 2) fotoğrafında ise insan figürü yanı başındaki büyük heykel karşısında küçülmektedir. Heykelin kapladığı alan ve kütlesel ağırlığı, kadının gündelik eylemiyle karşı karşıya gelmektedir. Yani *Esztergom, Hungary (Three Boys Reading)* (1915) (Görsel 1) fotoğrafının ağırlığı figürler arasındaki yakınlık üzerinden kurulurken, kadın figürünün bulunduğu *Budapest (Large Statue and Woman Reading on Stool)* (1971) (Görsel 2) fotoğrafında mekânsal öğeler ve göstergeler daha belirleyici rol oynamaktadır. Bu durum, Kertész'in aynı temayı farklı dönemlerde farklı insanlarla ele aldığını ve okuma eylemini iki fotoğrafta farklı özne-mekân ilişkileri içerisinde temsil ettiğini net biçimde göstermektedir.

Roger Chartier, *Kitapların Düzeni* adlı çalışmasında okumanın yalnızca zihinsel bir etkinlik olarak değerlendirilemeyeceğini; bedenin de okuma sürecine katıldığını ve okumanın belirli bir mekân içerisinde kişinin kendisiyle ya da başkalarıyla kurduğu ilişki üzerinden gerçekleştiğini belirtmektedir (Chartier, 1994, s. 8). Chartier'in bu çıkarımı, Kertész'in iki fotoğrafındaki temel farklılığın okunan metnin yanı sıra okuyan bedenlerin mekân içerisindeki konumları ve birbirleriyle kurdukları ilişkiler üzerinden değerlendirilmesine de olanak tanımaktadır. *Esztergom, Hungary (Three Boys Reading)* (1915) (Görsel 1) fotoğrafında üç çocuğun bedenleri aynı kitap etrafında birbirine yaklaşırken okuma fiziksel olarak paylaşılan bir deneyime dönüşmektedir. *Budapest (Large Statue and Woman Reading on Stool)* (1971) (Görsel 2) fotoğrafında ise tek başına okuyan kadın, kamusal mekân içerisinde kendi bedeni ve metin arasında daha kişisel bir ilişki kurmaktadır. Bu bağlamda Kertész'in fotoğrafları, Chartier'in okumanın beden, mekân ve diğer insanlarla kurulan ilişkiler içerisinde gerçekleştiğine ilişkin yaklaşımıyla iki açından da paralellik göstermektedir.

Bu farklılıklar içerisinde kent mekânının özellikle *Budapest (Large Statue and Woman Reading on Stool)* (1971) (Görsel 2) fotoğrafında daha görünür hale gelmesi, modern yaşamla kurulabilecek bir ilişkiye de işaret etmektedir. Georg Simmel'e göre modern yaşamın temel sorunlarından biri, bireyin "kendi varoluşunun bağımsızlığını ve bireyselliğini koruma çabasıdır" (Simmel, 2002, s. 11).

Bu iddia, Kertész'in *Budapest (Large Statue and Woman Reading on Stool)* (1971) (Görsel 2) fotoğrafında yer alan tekil okurun kamusal alan içerisindeki konumunu değerlendirmek açısından önemli bir perspektif sunmaktadır. Geniş bir kamusal mekân içerisinde kendi okuma deneyimine yönelen figür, kalabalık kent yaşamı içerisinde bireyin kendisine ait bir alan oluşturma ve bireyselliğini koruma çabasını düşündürmektedir.

Fotoğrafların üretildiği tarihsel koşullar da iki görüntü arasındaki farklılığın değerlendirilmesi açısından oldukça önemli ipuçları sunmaktadır. Varsa (2023, s. 284), I. Dünya Savaşı öncesinde Macaristan'daki tarım işçilerinin ekonomik ve toplumsal koşullarının oldukça ağır olduğunu; toprak dağılımındaki eşitsizliğin yoksullaşmış küçük toprak sahiplerinin ve topraksız köylülerin sayısını artırdığını belirtmektedir. Savaşın başlamasıyla birlikte söz konusu koşullar daha da ağırlaşmış ve gıda sıkıntısı 1914 yılının sonbaharından itibaren görülmeye başlanmıştır (Varsa, 2023, s. 284). Bu tarihsel arka plan, *Esztergom, Hungary (Three Boys Reading)* (1915) (Görsel 1) fotoğrafında iki çocuğun çıplak ayaklı, bir çocuğun ise yırtık pantolonla görüntülenmesi ve üç çocuğun tek bir kitabı paylaşmasıyla birlikte düşünüldüğünde, fotoğraftaki yoksulluk ve dayanışma göstergelerinin yorumlanmasına tarihsel bir zemin sunmaktadır. Aradan geçen elli altı yılın ardından çekilen *Budapest (Large Statue and Woman Reading on Stool)* (1971) (Görsel 2) fotoğrafının ise başka bir toplumsallığı yansıttığına işaret etmektedir. Zimmermann (2023, s. 80), 1960'lar ve 1970'lerde Macaristan'da kadınların endüstriyel iş gücüne katılımının arttığını ve bu gelişmenin devlet sosyalizmi dönemindeki ekonomik kalkınma politikalarının bir parçasını oluşturduğunu belirtmektedir. 1970'lerin başında yalnızca hafif sanayide 193.000 kadının çalışıyor olması, kadınların çalışma hayatındaki artan görünürlüğünü ortaya koyan dikkat çekici verilerden biridir (Zimmermann, 2023, s. 80). Bu bağlamda *Budapest (Large Statue and Woman Reading on Stool)* (1971) (Görsel 2) fotoğrafında kısa saçları, mini elbisesi ve topuklu ayakkabılarıyla kamusal kent mekânında tek başına bir şeyler okuyan kadın figürü, dönemin kentleşen ve dönüşen toplumsal yapısı içerisinde kadınların kamusal yaşamdaki artan görünürlüğüyle birlikte değerlendirilebilir.

6. Sonuç

Bu çalışmanın ortaya koyduğu temel noktalardan biri, Kertész'in On Reading projesinde okuma eyleminin bireyin toplumsal çevresiyle kurduğu ilişkinin değişkenliğini görünür kılmasıdır. Aynı gündelik eylemin farklı dönemlerde yeniden fotoğraflanması, okumanın beden, mekân, nesneler ve toplumsal koşullar tarafından yeniden biçimlendirilen bir deneyim olduğunu düşündürmektedir. Bu yönüyle On Reading adlı fotoğraf. projesi, gündelik yaşamın zaman içerisindeki dönüşümlerinin izlenebildiği görsel bir arşiv olarak da değerlendirilebilir.

İki fotoğraf arasındaki elli altı yıllık mesafe, benzer bir eylemin farklı tarihsel koşullar içerisinde yeni anlamlar kazanabildiğini ortaya koymaktadır. Okuma eylemi, değişen toplumsal konumlar, kamusal davranış biçimleri ve bireyin çevresiyle kurduğu ilişkiler doğrultusunda farklılaşmaktadır.

Çalışmada tarihsel kaynaklardan yararlanılması, görüntülerde yer alan bedenlerin, giysilerin, nesnelerin ve mekânların üretildikleri dönemin toplumsal koşullarıyla birlikte değerlendirildiğinde farklı anlamlar kazandığını göstermektedir. Bu durum, fotoğrafın tarihsel bilgiyle ilişkilendirildiğinde toplumsal bağlamın anlaşılmasına katkı sağlayabilen bir görsel belge olarak değerlendirilmesine olanak sağlamaktadır.

Çalışmanın iki fotoğrafla sınırlı olması, projenin tamamına ve Budapeşte'nin tarihsel süreç içerisinde değişen kültürel ve toplumsal dinamiklerine ilişkin genelleyici sonuçlara ulaşılmasını sınırlandırmaktadır. Ve iki görüntü arasında kurulan karşılaştırma, On Reading fotoğraf projesi içerisinde tekrar eden okuma temasının zaman, beden, mekân ve toplumsal bağlamla birlikte çok daha farklı anlamlar kazanabildiğini açıkça göstermektedir.

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A GENERAL OVERVIEW FOR TÜRKİYE-HUNGARY INDUSTRIAL RELATIONS FOR STRATEGIC COOPERATION

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Abstract
Türkiye and Hungary share deep-rooted ties spanning centuries across political, historical, social, cultural, and economic dimensions. Historical and social bonds, geopolitical locations, and economic activities render each state significant to the other in many areas that are ranging from production to economic cooperation. The aim of this study is to provide a general overview of events, institutions, and sectors that facilitate strategic cooperation between Türkiye and Hungary. This study offers a guidance to those wishing to explore opportunities in both countries. Following 2008 International Monetary Fund (IMF) crisis, "Eastern Opening" policy was adopted in 2010 by Hungary. This situation has elevated importance of cooperation with Organization of Turkic States (OTS) and particularly Türkiye for Hungary. Ties between two countries are further strengthened through opening institutions such as Hungary Investment Promotion Association (HIPA) in 2014 and Hungary Export Promotion Association (HEPA) in 2015. There is $6 billion export target between two states. HEPA reveals that, trade volume between Türkiye and Hungary has reached significant levels nowadays. Furthermore, active cooperation, projects, and engagement are taking place across various sectors, including, industrial manufacturing projects, renewable and alternative energy, infrastructure, logistics and transport, agriculture, tourism, information and communication technologies, and environment. Hungary’s low corporate tax rates, investment incentives, and a strong logistics infrastructure facilitate access to the European market for Turkish companies. Furthermore. Türkiye offers strong opportunities within the framework of Hungary's vision of opening up to the East, while Hungary serves as a strategic production and investment hub for Turkey in Central Europe and offers competitive advantages in terms of integration into EU value chains. The study reveals that the two states largely play complementary roles for their industry visions.
Keywords: Türkiye-Hungary, Industrial Relations, Strategic Cooperation.

EVALUATION OF THE INTERNATIONAL MOBILITY ATTRACTIVENESS OF LEADING UNIVERSITIES IN SEVEN CENTRAL EUROPEAN COUNTRIES (CEC) CONSIDERING ENGINEERING AND TECHNOLOGY USING THE MABAC METHOD

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Abstract
In today's world, gaining academic experience globally is crucial. Trough planning part of university education abroad or undertaking researcher mobility oppourtunities in different countries at the higher education level enhances international networking and contributes to the improvement of academic studies. Students and researchers evaluate many factors when choosing a country to study or work. The academic competence and success of the university, as well as economic, social, and environmental factors of the city where the university is located is some crucial points while determining the university. The motivation for this study is to provide a guide for individuals who wish to choose universities in Central European Countries (CEC). In this study, six criteria influencing university selection were identified as a result of a literature review which are Quacquarelli Symonds (QS) ranking of universities, Cost of Living Index, Health Care Index, Crime Index, Pollution Index, and Traffic Index. QS rankings are available for eight CEC except Liechtenstein. But there is no data regarding to the other criteria from Numbeo data platform for Slovenia and Liechtenstein. Therefore, acocording to this six criteria seven suitable CEC were identified which have data belongs to the year 2026. These countries are Austria, Czechia, Germany, Hungary, Poland, Slovakia and Switzerland. The university ranked first in the QS ranking to subject Engineering and Technology in each country was selected as the alternative. These universities are Vienna University of Technology (TU Wien), Czech Technical University in Prague (CTU), Technical University of Munich (TUM), Budapest University of Technology and Economics (BME), Warsaw University of Technology (WUT), Slovak University of Technology in Bratislava (STU), ETH Zurich (Swiss Federal Institute of Technology Zurich). Using the Multi-Attributive Border Approximation Area Comparison (MABAC) method that is a multi- attribute decision-making (MADM) method, and evaluating the criteria with equal weighting, the preference ranking of these seven universities is as follows: TUM, TU Wien, CTU, ETH Zurich, WUT, STU and BME. As a second scenario, if the cost-of-living criterion is considered as the main component with a 50% weighting, and the other five criteria are evaluated with equal weighting, the preference ranking of these 7 universities would be as follows: TUM, CTU, TU Wien, STU, WUT, BME and ETH Zurich.
Keywords: University Selection, Graduate Studies, Central European Countries (CEC), Multi-attribute Decision Making (MADM), Multi-Attributive Border Approximation Area Comparison (MABAC)

TRAVMATİK KAYIP VE YASI YENİDEN DÜŞÜNMEK: SALUTOJENİK MODEL İLE SOSYAL HİZMETE YENİ AÇILIMLAR

RETHINKING TRAUMATIC LOSS AND GRIEF: NEW PERSPECTIVES ON SOCIAL WORK WITH THE SALUTOGENIC MODEL

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ÖZET
Travmatik kayıp, bireyin ani ve beklenmedik bir ölüm sonrasında hem yasın duygusal etkileriyle hem de travmatik olayın yarattığı psikolojik sarsıntıyla eş zamanlı olarak baş etmeye çalıştığı çok boyutlu bir uyum sürecidir. Bu süreçte bireyin güvenlik algısı, benlik bütünlüğü, yaşamın anlamına ilişkin temel varsayımları ve sosyal ilişkileri önemli ölçüde etkilenebilmektedir. Buna karşın kayıp ve yas alanındaki çalışmaların önemli bir bölümü, patolojik belirtiler ve risk etmenleri üzerine odaklanırken bireyin güçlü yönleri ve iyileşme kapasitesi görece sınırlı biçimde ele alınmaktadır. Bu çalışmanın amacı, travmatik kayıp ve yas sürecini Antonovsky'nin salutojenik modeli doğrultusunda yeniden değerlendirerek modelin sosyal hizmet uygulamalarına sağlayabileceği kavramsal katkıları ortaya koymaktır. Çalışma, ulusal ve uluslararası literatür temelinde gerçekleştirilen kuramsal bir derleme niteliğindedir. İlk olarak travmatik kayıp ve yas olgusu, yas ve travma yaklaşımlarının kesişiminde ele alınmış; ardından salutojenik modelin temel kavramları olan bütünlük duygusu, anlaşılırlık, yönetilebilirlik ve anlamlılık boyutları açıklanmıştır. Son aşamada ise modelin mikro, mezzo ve makro düzey sosyal hizmet uygulamalarına olası yansımaları tartışılmıştır. Çalışma sonucunda salutojenik modelin; travmatik kaybı yalnızca risk faktörleri ve psikopatolojik belirtiler üzerinden değil, bireysel psikolojik sağlamlık, baş etme kapasitesi, sosyal destek sistemleri ve yaşamın yeniden anlamlandırılması odağında ele alan bütüncül bir perspektif sunduğu tespit edilmiştir. Sosyal hizmetin güçlendirme yaklaşımı ile bir örtüşme sergileyen bu modelin travmatik kayıp odağında yürütülen sosyal hizmet uygulamalarına yenilikçi bir bakış açısı kazandıracak bir yaklaşım olduğu öngörülmektedir. Çalışma salutojenik modelin sosyal hizmet alanında travmatik kayıplardan kaynaklı yas uygulamalarında kullanımına dair önerilerle tamamlanmıştır.
Anahtar Kelimeler: Salutojenik model, sosyal hizmet, kayıp, yas, travma, güçlendirme.

ABSTRACT
Traumatic loss is a multidimensional coping process in which an individual attempts to deal with both the emotional effects of grief and the psychological shock caused by the traumatic event following a sudden and unexpected death. During this process, the individual's perception of security, self-integrity, fundamental assumptions about the meaning of life, and social relationships can be significantly affected. However, a significant portion of research in the field of loss and grief focuses on pathological symptoms and risk factors, while the individual's strengths and capacity for recovery are addressed relatively limitedly. The aim of this study is to re-evaluate the traumatic loss and grief process in accordance with Antonovsky's salutogenic model and to reveal the conceptual contributions the model can make to social work practices. This study is a theoretical review based on national and international literature. First, the phenomenon of traumatic loss and grief is examined at the intersection of grief and trauma approaches; then, the fundamental concepts of the salutogenic model—sense of wholeness, intelligibility, manageability, and meaningfulness—are explained. Finally, the possible implications of the model for micro, mezzo, and macro-level social work practices are discussed. As a result of the study, the salutogenic model; It has been determined that this model offers a holistic perspective that addresses traumatic loss not only through risk factors and psychopathological symptoms, but also focusing on individual psychological resilience, coping capacity, social support systems, and the re-evaluation of life. This model, which aligns with the empowerment approach of social work, is expected to provide an innovative perspective on social work practices focused on traumatic loss. The study concludes with recommendations for the use of the salutogenic model in social work practices related to grief stemming from traumatic losses.
Keywords: Salutogenic model, social work, loss, grief, trauma, empowerment.

GİRİŞ

Ölüm, yaşam döngüsünün kaçınılmaz bir parçası olmakla birlikte birey ve aile sistemi üzerinde derin psikososyal etkiler bırakan deneyimlerden biridir (Thompson, 2002). Ölüm veya başka sebeplerden kaynaklı kayıplara verilen tepkiler sosyal, fiziksel, psikolojik, davranışsal olabilmektedir (Aslan ve Yelboğa, 2024). Yakın bir kişinin kaybı ise çoğu zaman yas sürecini başlatan doğal bir yaşam olayı olarak değerlendirilse de ölümün ani, beklenmedik veya şiddet içeren sebepler veya koşullar altında gerçekleşmesi, bu deneyimin yalnızca yas olgusu ile açıklanmasını güçleştirmektedir. Örneğin intihar, cinayet, trafik kazaları, doğal afetler, savaşlar ya da beklenmedik tıbbi olaylar sonucunda meydana gelen ölümler, geride kalan bireyler açısından hem sevilen kişinin kaybına ilişkin yoğun duygusal acıyı hem de olayın tehdit edici niteliğine bağlı travmatik tepkileri aynı anda ortaya çıkarabilmektedir (Herman, 2014). Bu yönüyle travmatik kayıplar, yas ve psikolojik travmanın kesişiminde yer alan özgün bir deneyim alanı oluşturmaktadır.

Son yıllarda travma ve yas alanındaki çalışmaların sayısı önemli ölçüde artmış olmakla birlikte yas literatürü daha çok kayıp sonrasında gelişen duygusal, bilişsel ve davranışsal uyum süreçlerine odaklanmaktadır. Travma literatürü ise bireyin yaşam bütünlüğünü tehdit eden olaylara verdiği psikolojik ve fizyolojik tepkileri açıklamaktadır. Oysa ani ve beklenmedik ölümler sonrasında yaşanan deneyim hem yasın hem de travmanın özelliklerini aynı anda taşıyabilmektedir (Neria ve Litz, 2004). Bu nedenle söz konusu yaşantının yalnızca yas ya da yalnızca travma perspektifiyle değerlendirilmesi, bireyin yaşadığı çok boyutlu sürecin bütüncül biçimde anlaşılmasını sınırlandırmaktadır.

Kavramın sınırları tam olarak belirginleşmese de (Ruppert, 2005) bu çalışma kapsamında kayıp travması; bireyin kendisi için anlamlı bir kişinin ani veya beklenmedik ölümüyle karşılaşması sonucunda ortaya çıkan; kaybın yol açtığı yas tepkileri ile tehdit, çaresizlik ve yoğun korku gibi travmatik yaşantıların iç içe geçtiği karmaşık bir süreç olarak ele alınmaktadır (Kachler, 2021). Böyle bir yaklaşım, kayıp deneyiminin psikopatoloji ekseni dışında bireyin uyum kapasitesi ve iyileşme potansiyeli açısından da değerlendirilmesine olanak sağlamaktadır.

Travmatik kayıpların anlaşılmasına yönelik yaklaşımlar uzun yıllar boyunca ağırlıklı olarak patoloji, risk faktörleri ve semptomların azaltılması üzerine kurulmuştur. Buna karşın son yıllarda pozitif psikoloji ve güç temelli yaklaşımların gelişmesiyle birlikte bireylerin zorlayıcı yaşam olaylarına rağmen sağlıklarını nasıl koruyabildiklerine odaklanan modeller daha fazla ilgi görmeye başlamıştır. Aaron Antonovsky tarafından geliştirilen salutojenik model de bu yaklaşımlardan biridir. Model, bireylerin hastalanmalarının nedenlerinden çok, sağlıklarını korumalarını sağlayan bireysel ve çevresel kaynakları açıklamayı amaçlamakta; özellikle "tutarlılık duygusu" (sense of coherence) kavramı aracılığıyla stresli yaşam olayları karşısındaki uyum süreçlerini açıklamaktadır (Antonovsky, 1997). Anlaşılırlık, yönetilebilirlik ve anlamlılık boyutlarından oluşan bu yapı, travmatik kayıp sonrasında bireylerin yaşadıkları deneyimi anlamlandırmalarına, mevcut kaynaklarını harekete geçirmelerine ve psikososyal iyilik hâllerini sürdürmelerine katkı sağlayabilecek önemli bir kavramsal çerçeve sunmaktadır.

Kayıp ve yas olgusuna ilişkin sosyal hizmet literatürü son yıllarda giderek zenginleşmeye devam etse de (Yelboğa, 2023b), hayatın yeniden inşasını esas alan farklı modellere de ihtiyaç bulunmaktadır (Thompson, 2002). Bu bağlamda salutojenik modelin travmatik kayıp bağlamında nasıl kullanılabileceğine yönelik kavramsal değerlendirmeler oldukça sınırlı kalmıştır. Oysa bireylerin risk ve patolojiye odaklanmak yerine mevcut güçlerini, baş etme kaynaklarını ve psikososyal iyilik hâllerini merkeze alan salutojenik yaklaşımın, kayıp ve yas uygulamalarına önemli katkılar sunma potansiyeli bulunmaktadır. Buna karşın modelin sosyal hizmet alanındaki görünürlüğü ve kullanımına ilişkin akademik tartışmalar henüz yeterli düzeye ulaşmamıştır.

Türkiye'de salutojenik modeli ele alan çalışmaların sayısı oldukça sınırlıdır. Bu kapsamda Uysal Toraman ve Eren (2021) tarafından hazırlanan çalışma, modeli yaşlı sağlığı bağlamında tanıtan öncü çalışmalardan biri olmakla birlikte değerlendirmelerini ağırlıklı olarak hemşirelik disiplini çerçevesinde yürütmüştür. Dolayısıyla salutojenik modelin sosyal hizmetin kayıp ve yas uygulamalarıyla ilişkilendirildiği kapsamlı kuramsal çalışmaların eksik olduğu görülmektedir.

Sosyal hizmet uygulamalarında yas çalışmaları büyük ölçüde risk, patoloji ve semptom azaltmaya odaklanmaktadır. Buna karşın bireyin güçlü yönlerini, uyum kapasitesini ve sağlığı koruyucu kaynaklarını merkeze alan modeller sınırlı düzeyde tartışılmıştır (Mason, Tofthagen, ve Buck, 2020).

Söz konusu sebeple bu çalışmanın temel amacı, kayıp travması kavramını yas ve psikolojik travma kuramlarının kesişiminde ele almak; salutojenik modelin bireylerin travmatik kayıp sonrasında geliştirdikleri uyum ve dayanıklılık süreçlerine sağlayabileceği katkıları tartışmak ve bu yaklaşımın sosyal hizmetin kayıp ve yas uygulamalarındaki olası kullanım alanlarını kavramsal bir çerçevede değerlendirerek sosyal hizmet teori ve uygulamasına açılımlar getirmektir. Bu amaç doğrultusunda, öncelikle çalışmanın kavramsal temelini oluşturan kayıp ve yas olguları ele alınmış; ardından salutojenik model, temel kavramları ve bileşenleri çerçevesinde açıklanmış; son bölümde ise modelin sosyal hizmetin kayıp ve yas uygulamalarına sağlayabileceği olası katkılar güncel literatür ışığında tartışılarak uygulamaya ve gelecekte yapılacak araştırmalara yönelik öneriler sunulmuştur.

YAS SÜRECİ VE KAYIP TRAVMASI

Yas, bireyin önemli bir kayıp deneyiminin ardından geliştirdiği duygusal, bilişsel, davranışsal ve bedensel tepkilerin tümünü içeren çok boyutlu bir uyum süreci olarak değerlendirilmektedir. Bir başka ifade ile bireyin önemli gördüğü bir kişi, ilişki, rol ya da değerin kaybı sonrasında ortaya çıkan doğal bir uyum sürecidir (Bowlby, 2006; Kast, 2013). Psikanalitik kuramın öncülerinden Freud (2014), yası sevilen bir kişinin ölümüne ya da birey için anlam taşıyan soyut bir değerin yitirilmesine verilen doğal bir tepki olarak tanımlamaktadır. Günümüzde ise yas, bireyin kayıp sonrasında yeni yaşam koşullarına uyum sağlamaya çalıştığı dinamik ve çok boyutlu bir süreç olarak ele alınmaktadır.

Yas olgusuna ilişkin farklı kuramsal yaklaşımlar, süreci farklı açılardan açıklamaktadır. Psikanalitik bakış açısına göre yas, bireyin kaybedilen kişi ya da nesneye yönelik duygusal bağını zaman içinde yeniden düzenleyerek yaşamına uyum sağlamasını içeren bir süreçtir. Bağlanma kuramı ise yası, güvenli bağ kurulan kişinin kaybı sonrasında bağlanma sisteminin etkinleşmesiyle ortaya çıkan doğal bir ayrılık tepkisi olarak ele almakta ve bireyin bu sistemini yeni koşullara göre yeniden organize etmesi gerektiğini vurgulamaktadır (Bowlby, 2006). Bir başka görüşe göre yas, kayba ilişkin zihinsel temsiller ile bireyin bu yaşantıya uyum sağlama çabaları arasında sürekli devam eden dinamik bir etkileşim süreci içinde ilerlemektedir (Horowitz, 2001).

Güncel yas yaklaşımları, yasın belirli ve doğrusal evrelerden oluşan tek tip bir süreç olmadığını, bireyin özellikleri, kaybın niteliği ve çevresel koşullar doğrultusunda farklı biçimlerde ilerleyen dinamik bir uyum süreci olduğunu kabul etmektedir (Kersting vd., 2001). Bu doğrultuda günümüzde yasın yalnızca duygusal tepkiler üzerinden değil, bireyin kaybı bilişsel, duygusal ve varoluşsal düzeyde nasıl anlamlandırdığı üzerinden de değerlendirildiği görülmektedir. Kaybın yaşam öyküsüne anlamlı bir biçimde entegre edilebilmesi, uyum sürecinin sağlıklı ilerlemesinde önemli bir rol oynamaktadır.

Travmatik yas ise ölümün ani, beklenmedik ya da tehdit edici koşullar altında gerçekleşmesi sonucunda ortaya çıkan ve yas tepkileri ile travmatik stres belirtilerinin eş zamanlı yaşandığı daha karmaşık bir uyum sürecini ifade etmektedir (Maercker, 2009; Herman, 2014). Bu durumda birey, sevilen kişinin yokluğuna uyum sağlamaya çalıştığı gibi olayın yarattığı yoğun korku, çaresizlik ve güven duygusundaki sarsılmayla da baş etmeye çalışmaktadır. Bu nedenle travmatik kayıplar, kaybın hem duygusal hem de bilişsel düzeyde işlenmesini güçleştiren ve iyileşme sürecini zorlaştıran özellikler taşımaktadır. Bu çerçevede travmatik kayıp, yas ve travma süreçlerinin birbirinden bağımsız ele alınamayacağı özgün bir deneyim olarak değerlendirilmektedir. Travma yaklaşımı, tehdit edici yaşantıların bireyin bilişsel ve duygusal işleyişi üzerindeki etkilerini açıklarken; yas yaklaşımı, kaybın ardından gelişen uyum ve yeniden yapılanma süreçlerine odaklanmaktadır. Travmatik kayıp deneyiminde ise bu iki süreç iç içe geçmekte, bireyin hem travmatik yaşantıyı hem de kaybı eş zamanlı olarak anlamlandırmasını ve yaşamına uyarlamasını gerektirmektedir. Yas sürecinde bireyin gündelik işlevselliğinde belirgin değişiklikler olabilir ancak bu durumun tek başına patolojik olarak değerlendirilmemeli hatta yasın doğal seyri kesintiye uğratılmamalı zira bu zararlı bile olabilmektedir (Freud, 2014). Dolayısıyla hangi aşamada ve nasıl doğal yas seyrinden çıkıldığı sorusu önem kazanmaktadır.

Kayıp travması, ani ve beklenmedik ölümler sonucunda ortaya çıkan hem yasın duygusal acısını hem de travmatik olayın yarattığı tehdit ve sarsıntıyı bir arada barındıran karmaşık bir süreç (Öztürk ve Derin, 2020) olduğu için klasik yas açıklamaları ya da yalnızca travma kuramları kayıp travmasının karmaşıklığını tek başına karşılayamamaktadır. Ani, şiddet içeren veya beklenmedik ölümler bireyin güvenlik, kontrol ve anlam algısını derinden sarsmaktadır (Herman, 2014). Travmatik kayıplarda sevilen kişinin ölümü dışında ölümün şekli de etkilidir.

Örneğin ölümün beklenmedik olması, şiddet içeren ya da sarsıcı biçimde gerçekleşmesi de bireyin uyum sürecini önemli ölçüde güçleştirebilmektedir. Bu tür yaşantılar, bilişsel süreçlerde bozulma, benlik algısında sarsılma ve yoğun duygusal zorlanmalarla ilişkilendirilmektedir. Travmatik kayıp deneyiminde birey, bir yandan kaybın gerçekliğini kabul ederek yas sürecine uyum sağlamaya çalışırken diğer yandan da travmatik olayın yarattığı zihinsel ve duygusal etkileri anlamlandırma ve bütünleştirme çabası içindedir. Yas ve travmanın eş zamanlı yaşanması, kaybın hem duygusal hem de bilişsel düzeyde işlenmesini zorlaştırmakta; bu nedenle travmatik kayıp yaşayan bireylerde yas tepkileri daha ağır seyredebilmekte ve iyileşme süreci uzayabilmektedir (Kersting vd., 2001).

Travmatik kaybı diğer kayıp deneyimlerinden ayıran temel özellik, ölümün birey tarafından anlamlandırılmasında yaşanan zorluktur. Güç ve beklenmedik bir olay olarak yaşanmasıdır. Bu süreçte birey, kaybın neden gerçekleştiğini ve yaşamını bundan sonra nasıl sürdüreceğini anlamlandırmaya çalışırken benlik algısı, dünyaya yönelik temel güven duygusu ve sosyal ilişkileri önemli ölçüde etkilenebilmektedir. Travmatik kayıp yaşayan bireylerde ölüm anına ilişkin istemsiz ve yineleyici anılar, kaybı hatırlatan uyaranlardan kaçınma, yoğun öfke, suçluluk ve kırılganlık gibi duygusal tepkiler görülebilmektedir. Bunun yanı sıra ölümü kabullenmede güçlük, kayba ilişkin anılardan uzak durma ile kaybedilen kişiye aşırı bağlılık arasında gidip gelme, yaşamın anlam ve amacına yönelik inançların zayıflaması ve sosyal ilişkilerden geri çekilme gibi tepkiler de bu sürece eşlik edebilmektedir (Maercker, 2009).

Ani ve beklenmedik ölümler, birey üzerinde en güçlü travmatik etki yaratan yaşam olayları arasında yer almaktadır. Ölümün şiddet, kaza, afet ya da benzeri tehdit edici koşullar altında gerçekleşmesi, kaybın yalnızca yas sürecini değil, aynı zamanda travmatik stres tepkilerini de tetikleyebilmektedir. Bu nedenle travmatik kayıplarda birey, sevilen kişinin yokluğuna uyum sağlamaya çalışırken bir yandan da olayın yarattığı korku, dehşet ve kontrol kaybıyla baş etmek zorunda kalmaktadır. Bu durum, travmaya eşlik eden kayıpları klasik yas deneyimlerinden ayıran temel özelliklerden biridir. Travmatik kayıp yaşayan bireylerde kayıp anısına ilişkin istemsiz ve yineleyici zihinsel imgeler, olayı çağrıştıran kişi, yer ve durumlardan kaçınma, sürekli tetikte olma hâli, yoğun suçluluk ve sorumluluk duyguları, ölümü anlamlandırmada güçlük, benlik algısında zedelenme ve temel güven duygusunun sarsılması gibi tepkiler görülebilmektedir. Bu belirtiler, travmanın neden olduğu bilişsel ve nöropsikolojik etkiler ile yasın ortaya çıkardığı yoğun duygusal acının birbirini beslediği karmaşık bir uyum sürecine işaret etmektedir. Bu bağlamda travmatik kayıp, bireyin yalnızca bir yakınının kaybıyla değil, aynı zamanda güvenlik, bağlılık ve yaşamın anlamına ilişkin temel varsayımlarındaki sarsılmayla da yüzleşmesine neden olmaktadır. Yaşanan bu çok boyutlu kırılma, bireyin benlik algısını, ilişkilerini ve yaşamını anlamlandırma biçimini yeniden yapılandırmasını gerektirmektedir (Ruppert, 2005).

Dolayısıyla travmatik kaybın anlaşılması ve değerlendirilmesi, yalnızca yas ya da yalnızca travma perspektifiyle sınırlandırılamamaktadır. Bu deneyimin çok katmanlı yapısı, her iki yaklaşımın birlikte ele alındığı bütüncül bir bakış açısını gerekli kılmaktadır. Bu bütüncül değerlendirmeyi destekleyen yaklaşımlardan biri olan salutojenik model ise bireyin yaşadığı ağır kayıp ve travmalara rağmen sahip olduğu güç kaynaklarını harekete geçirerek uyum sağlayabilme ve iyilik hâlini yeniden inşa edebilme potansiyeline odaklanmaktadır. Bu yönüyle model, travmatik kayıp ve yas alanında sosyal hizmet uygulamalarına önemli açılımlar sunmaktadır. Travmatik kayıp, yalnızca geçmişte yaşanan acı verici bir yaşam olayını değil, bireyin geleceğe ilişkin beklentilerini, benlik algısını ve yaşamın sürekliliğine dair temel kabullerini de derinden etkileyen bir deneyimdir. Travmanın güvenlik, öngörülebilirlik ve kontrol duygusunu zedelemesi, yas sürecinin doğal uyum mekanizmalarını güçleştirebilmekte ve kaybın anlamlandırılmasını zorlaştırabilmektedir. Bu nedenle travmatik kaybın değerlendirilmesinde yalnızca patolojiye odaklanmak yerine, bireyin uyum kapasitesi, dayanıklılığı ve iyileşme potansiyelinin de dikkate alınması önem taşımaktadır. Bu bağlamda salutojenik model, bireylerin ağır kayıp ve travmatik yaşantılara rağmen işlevselliklerini sürdürebilmelerini ve yaşamla yeniden bağ kurabilmelerini açıklayan önemli bir yaklaşım sunmaktadır. Modelin temel bileşenleri olan anlaşılırlık, yönetilebilirlik ve anlamlılık, travmatik kaybın yarattığı sarsıntının ardından bireyin yaşamını yeniden yapılandırmasını destekleyen koruyucu kaynaklar olarak değerlendirilmektedir (Antonovsky, 1997; Wiesmann, 2013).

SALUTOJENİK MODEL

Salutojenik model, Aaron Antonovsky tarafından geliştirilen ve bireylerin yoğun stres ya da zorlu yaşam deneyimlerine rağmen sağlıklarını ve iyi oluşlarını nasıl sürdürebildiklerini açıklamayı amaçlayan bir yaklaşımdır. Salutojenik model, Aaron Antonovsky tarafından 1970'li yıllarda geliştirilmiş olup bireylerin yoğun stres ve olumsuz yaşam deneyimlerine rağmen sağlıklarını nasıl koruyabildiklerini açıklamayı amaçlayan bir yaklaşımdır. Model, hastalığın nedenlerine odaklanan patojenik anlayıştan farklı olarak sağlığı destekleyen bireysel ve çevresel kaynakları merkeze almaktadır. Antonovsky, bu yaklaşımı geliştirirken Holokost'tan sağ kurtulan kadınlarla yürüttüğü araştırmalarda, ağır travmatik yaşantılara karşın bazı bireylerin ruhsal iyilik hâllerini koruyabildiğini gözlemlemiş ve bu durumun altında yatan koruyucu etmenleri açıklamaya yönelmiştir. Bu doğrultuda model, insanların neden hastalandığından çok, zorlu yaşam olaylarına rağmen nasıl sağlıklı kalabildiklerine odaklanmaktadır. Hastalıkların ortaya çıkış nedenlerine odaklanan patojenik bakış açısının aksine, bu model bireyin sağlığını korumasını ve geliştirmesini sağlayan kişisel, sosyal ve çevresel kaynakları ön plana çıkarmaktadır (Antonovsky, 1997).

Modelin merkezinde yer alan bütünlük duygusu (sense of coherence), bireyin yaşam olaylarını algılama ve onlarla baş etme biçimini açıklayan temel kavram olup anlaşılırlık, yönetilebilirlik ve anlamlılık olmak üzere üç bileşenden oluşmaktadır.

Anlaşılırlık, bireyin yaşamında karşılaştığı olayları düzenli, öngörülebilir ve bilişsel olarak kavranabilir görmesini ifade etmektedir. Ancak travmatik kayıplar, beklenmedik ve sarsıcı yapıları nedeniyle bireyin dünyaya ilişkin temel varsayımlarını zedeleyebilmekte ve yaşanan olayın anlamlandırılmasını güçleştirebilmektedir. Salutojenik yaklaşım, bireyin kayıp deneyimini bilişsel olarak yeniden yapılandırmasını, yaşanan olayın nedenlerini ve sonuçlarını zaman içinde anlamlandırmasını destekleyerek bütünlük duygusunun yeniden oluşturulmasına katkı sağlamaktadır (Antonovsky, 1997).

Yönetilebilirlik**,** bireyin yaşamındaki güçlüklerle baş edebilmek için gerekli kişisel ve çevresel kaynaklara sahip olduğuna ilişkin inancını yansıtmaktadır. Travmatik kayıp yaşayan bireylerde yoğun çaresizlik, kontrol kaybı ve belirsizlik duyguları, mevcut baş etme kapasitesinin yetersiz olduğu algısını güçlendirebilmektedir. Bu noktada aile ve sosyal çevreden alınan destek, profesyonel yardım hizmetleri, önceki baş etme deneyimleri ve bireysel güçlü yönler önemli koruyucu kaynaklar olarak öne çıkmaktadır (Antonovsky, 1997; Wiesmann, 2013). Sosyal hizmet uygulamalarında ise yönetilebilirlik, bireyin güçlü yönlerinin ortaya çıkarılması, sosyal destek ağlarının güçlendirilmesi, hizmet ve kaynaklara erişimin kolaylaştırılması ve etkili baş etme becerilerinin geliştirilmesi yoluyla desteklenmektedir.

Anlamlılık, bütünlük duygusunun motivasyonel yönünü oluşturarak bireyin yaşadığı güçlükleri yaşamın anlamlı bir parçası olarak değerlendirebilmesini ifade etmektedir. Travmatik kayıplar, bireyin yaşamın sürekliliğine, ilişkilerine ve geleceğe ilişkin anlam sistemini derinden sarsmakta; kaybın nedenine ve yaşamın bundan sonraki seyrine ilişkin sorgulamaları beraberinde getirmektedir. Salutojenik model, iyileşme sürecinde yalnızca kaybın kabul edilmesine değil, aynı zamanda bireyin yaşamına yeni anlamlar kazandırmasına ve yaşam amaçlarını yeniden yapılandırmasına da önem vermektedir. Bu süreç, kayıp sonrası ilişkilerin yeniden düzenlenmesini, yaşamla yeniden bağ kurulmasını ve psikolojik bütünlüğün güçlendirilmesini desteklemektedir. Bu yönüyle salutojenik model, travmatik kaybın yalnızca oluşturduğu risk ve belirtilere odaklanmamakta; bireyin sahip olduğu koruyucu kaynakları, dayanıklılık kapasitesini ve iyileşme potansiyelini görünür kılan bir çerçeve sunmaktadır. Travmatik kaybın duygusal ve bilişsel bütünlük üzerinde oluşturduğu sarsıntının onarılmasında, bütünlük duygusunun üç bileşeninin güçlendirilmesi bireyin uyum sürecini destekleyen temel mekanizmalardan biri olarak değerlendirilmektedir. Bu nedenle salutojenik model, travmatik kayıp alanında yürütülen sosyal hizmet müdahaleleri için önemli bir kavramsal dayanak oluşturmaktadır. Salutojenik yaklaşım, travmatik kayıp sonrasında bozulan psikolojik bütünlüğün yeniden yapılandırılmasına önemli katkılar sunmaktadır. Öncelikle, bireyin yaşadığı travmatik deneyimi bilişsel olarak anlamlandırmasını destekleyerek olayın daha anlaşılabilir bir çerçevede değerlendirilmesine yardımcı olmaktadır. Bunun yanında, bireyin sahip olduğu kişisel güçlü yönlerin, sosyal destek ağlarının ve çevresel kaynakların fark edilmesini ve etkin biçimde kullanılmasını teşvik ederek baş etme kapasitesini güçlendirmektedir. Ayrıca, kayıp sonrasında yaşamın yeniden anlamlandırılmasını destekleyerek bireyin geleceğe yönelik amaç ve motivasyon geliştirmesine katkı sağlamaktadır.

Anlamlılık duygusunun güçlenmesi, travmatik kayıp sonrasında uyum sürecinin en önemli bileşenlerinden biri olarak kabul edilmektedir (Antonovsky, 1997). Bu yönüyle salutojenik model, travmatik kaybı yalnızca ortaya çıkardığı belirtiler ve psikopatolojik sonuçlar üzerinden değerlendirmek yerine, bireyin iyileşme potansiyelini, dayanıklılığını ve mevcut kaynaklarını merkeze alan bütüncül bir bakış açısı sunmaktadır. Bu yaklaşım, travmatik kayıp alanında yürütülen sosyal hizmet uygulamalarında güçlendirme ve iyileşme odaklı müdahalelerin geliştirilmesine önemli bir temel oluşturmaktadır.

Genel Direnç Kaynakları (GRRs)

Salutojenik modele göre bireysel ve sosyal kaynaklar, bireyin stres yaratan yaşam olaylarıyla etkili biçimde başa çıkmasını sağlayan fiziksel, biyolojik, bilişsel, maddi ve sosyal nitelikteki koruyucu unsurları ifade etmektedir. Bu kaynaklar; ekonomik olanaklar, bilişsel kapasite, benlik saygısı, sosyal destek ağları, kültürel bağlar ile dini veya felsefi inançlar gibi bireyin hem kendi içinde hem de çevresinde bulunan maddi ve maddi olmayan varlıkları kapsamaktadır. Söz konusu kaynaklar, bireyin bütünlük duygusunu (Sense of Coherence) güçlendirerek stresörleri daha etkili biçimde yönetmesine ve sağlığını korumasına katkı sağlamaktadır. Bu nedenle bireysel ve sosyal kaynaklar, salutojenik yaklaşımın temel dayanaklarından biri olarak değerlendirilmektedir (Wiesmann ve Hannich, 2010).

Stresörler ve Gerilim

Salutojenik modelde stresörler, bireyin yaşamı boyunca karşılaştığı ve uyum sağlamasını gerektiren içsel ya da dışsal talepleri ifade etmektedir. Hastalık, kayıp, ekonomik güçlükler, rol değişimleri, doğal afetler veya diğer kritik yaşam olayları bireyin dengesini zorlayan stresörler arasında yer almakla birlikte, bu deneyimler tek başına olumsuz ya da patolojik sonuçlar doğuran etkenler olarak değerlendirilmez. Model, stresörleri yaşamın kaçınılmaz bir parçası olarak görmekte ve bireyin bu durumlara nasıl tepki verdiğine, hangi kaynakları kullanabildiğine ve yaşadığı deneyimi nasıl anlamlandırdığına odaklanmaktadır. Bu bağlamda stresörlerin ortaya çıkardığı gerilim, bireyin bütünlük duygusu ve sahip olduğu bireysel, sosyal ve çevresel kaynaklar doğrultusunda yönetilebildiğinde uyum ve gelişim için bir fırsata dönüşebilmektedir. Buna karşılık mevcut kaynakların yetersiz kalması ya da etkin biçimde kullanılamaması, gerilimin kronikleşmesine ve sağlık üzerinde olumsuz sonuçların ortaya çıkmasına neden olabilmektedir. Dolayısıyla salutojenik yaklaşım, stresörleri ortadan kaldırmayı değil, bireyin bu zorluklarla etkili biçimde baş edebilmesini sağlayacak koruyucu kaynakların güçlendirilmesini hedeflemektedir. Sağlık da bu perspektifte, hastalığın yokluğu ile sınırlı olmayan; bireyin yaşamın kaçınılmaz güçlüklerine rağmen denge kurabildiği, uyum sağlayabildiği ve iyi oluşunu sürdürebildiği dinamik bir süreç olarak ele alınmaktadır (Strümpfer, 1990; Perez-Wilson vd., 2021).

Sağlık-Hastalık Sürekliliği

Salutojenik modele göre sağlık, hastalık ve sağlığın birbirinden kesin sınırlarla ayrıldığı bir durum değil, bireyin yaşamı boyunca hareket ettiği dinamik bir sağlık-hastalık sürekliliğidir. Bu bakış açısı, sağlığın sürekli yeniden oluşturulan bir süreç olduğunu ve bireyin yaşamındaki stresörlerin her zaman olumsuz sonuçlar doğurmayabileceğini savunmaktadır. Stresin etkisi, bireyin sahip olduğu kişisel ve çevresel kaynaklar ile bu kaynakları kullanabilme kapasitesine bağlı olarak değişmektedir (Antonovsky, 1997 Modelin temelini Genel Dayanıklılık Kaynakları (Generalized Resistance Resources-GRR) ve Bütünlük Duygusu (Sense of Coherence-SOC) oluşturmaktadır. Genel Dayanıklılık Kaynakları; sosyal destek, bilgi, deneyim, özsaygı, ekonomik olanaklar, kültürel değerler ve yaşam deneyimleri gibi bireyin zorluklarla baş etmesini kolaylaştıran kaynakları kapsamaktadır. Ancak bu kaynakların varlığı tek başına yeterli olmayıp bireyin bunları etkin biçimde kullanabilmesi gerekmektedir. Bu noktada bütünlük duygusu belirleyici rol üstlenmektedir. Antonovsky'ye göre bütünlük duygusu; bireyin yaşamındaki olayları anlaşılabilir, yönetilebilir ve anlamlı olarak algılama kapasitesini ifade eden temel bir yönelimdir. Salutojenik model, sağlık geliştirme alanında da önemli bir yaklaşım olarak kabul edilmektedir. Model, sağlık hizmetlerinin odağını hastalıkların tedavisinden bireyin güçlü yönlerinin, baş etme kapasitesinin ve sağlık kaynaklarının geliştirilmesine kaydırmaktadır. Bu nedenle bireyin aktif katılımını, güçlendirilmesini ve yaşamı üzerindeki kontrolünü artırmayı hedefleyen sosyal hizmet anlayışıyla önemli ölçüde örtüşmektedir.

Özellikle travmatik yaşam olayları ve kayıp deneyimlerinde bireyin yalnızca yaşadığı sorunlara değil, iyileşmeyi destekleyen kişisel ve çevresel kaynaklarına odaklanması bakımından sosyal hizmet uygulamalarına önemli bir kavramsal temel sunmaktadır (García, 2011).
Literatürden yola çıkılarak salutojenik modelin temel bileşenleri ortaya çıkabilmektedir. Buna göre (Tablo 1) aşağıda söz konusu temel bileşenler, tanım ve örnek-özellikleri görülebilmektedir.

Tablo 1. Salutojenik Modelin Temel Bileşenleri

Ana Bileşen	Alt Bileşen / Boyut	Tanım	Örnek / Özellik
Tutarlılık Hissi (SOC)	**Anlamlandırılabilirlik** *(Comprehensibility)*	İçsel ve dışsal uyaranların mantıklı, düzenli, öngörülebilir ve anlaşılır olarak algılanması.	Yaşanan bir kriz durumunu belirsiz veya karmaşık görmek yerine, nedenini ve yapısını kavrayabilme.
	Yönetilebilirlik *(Manageability)*	Karşılaşılan talepleri ve yükleri karşılamak için yeterli kaynağa sahip olunduğuna dair inanç.	İçsel (özsaygı, beceri) veya dışsal (sosyal destek, aile) kaynaklara erişebileceğine güvenme.
	Anlamlılık *(Meaningfulness)*	Hayatın duygusal olarak bir anlam taşıdığı ve karşılaşılan zorlukların çaba göstermeye değer olduğu duygusu.	Yaşanan stresi bir yük değil, üstesinden gelinmeye değer bir mücadele/fırsat olarak görme. *(SOC'un en güçlü boyutudur.)*
Genel Direnç Kaynakları (GRRs)	Bireysel ve Sosyal Kaynaklar	Bireyin stresörlerle başa çıkmasını sağlayan fiziksel, biyolojik, maddi, bilişsel ve sosyal varlıklar.	Maddi imkanlar, zeka, sosyal destek ağları, kültürel bağlar, dini/felsefi inançlar ve benlik saygısı.
Stresörler ve Gerilim	İçsel/Dışsal Uyaranlar	Bireyin dengesini bozan, yanıt verilmesini gerektiren potansiyel tehditler veya talepler.	Kronik hastalıklar, ekonomik krizler, rol çatışmaları veya ani yaşam olayları.
Sağlık-Hastalık Sürekliliği	Sağlık/Hastalık Tayfı *(Dis-ease / Health-Ease)*	Sağlığı mutlak bir "hasta" veya "sağlıklı" durumu yerine, iki uç arasında sürekli değişen bir süreç olarak görme.	Bireyin kronik bir rahatsızlığı olsa dahi güçlü bir SOC ile yüksek iyilik haline sahip olabilmesi.

Kaynak: Antonovsky, 1997; Wiesmann ve Hannich, 2010; García, 2011; Perez-Wilson vd., 2021.

Salutojenik Modelin Sosyal Hizmet Uygulamalarına Olası Yansımaları

Sosyal hizmet mesleği, kayıp ve yas sürecinde bireylerin psikososyal iyilik hâllerini destekleyen, mevcut güçlü yönlerini görünür kılmayı ve çevresel destek sistemleriyle etkileşimlerini güçlendirmeyi merkeze alan bütüncül müdahale yaklaşımlarına yönelmektedir. Son yıllarda travma, yas ve güçlendirme ekseninde gelişen sosyal hizmet literatürü, yalnızca kayba bağlı sorunların ve risklerin belirlenmesine değil, aynı zamanda bireyin baş etme kapasitesinin, sosyal destek ağlarının ve mevcut kaynaklarının güçlendirilmesine odaklanmaktadır (Yelboğa, 2023a).
Türkiye'de kayıp ve yas alanında yürütülen araştırmalar ile uygulama temelli lisansüstü çalışmalar da sosyal hizmetin yas danışmanlığı, afet ve kitlesel kayıplar sonrasında psikososyal müdahaleler, sosyal destek mekanizmalarının güçlendirilmesi ve danışanların uyum süreçlerinin desteklenmesi gibi alanlarda giderek daha görünür bir rol üstlendiğini ortaya koymaktadır (Demir, 2020; Öztürk, 2021; Aydın, 2023). Bu gelişmeler, sosyal hizmet uygulamalarında yalnızca sorun ve semptom odaklı müdahalelerin değil, bireyin güçlü yönlerini, dayanıklılığını ve çevresel kaynaklarını merkeze alan yaklaşımların da önem kazandığını göstermektedir. Bu bağlamda salutojenik model, sosyal hizmetin güçlendirme yaklaşımıyla büyük ölçüde örtüşen ve kayıp ile yas sürecinde yürütülen müdahaleleri anlaşılırlık, yönetilebilirlik ve anlamlılık boyutları üzerinden yeniden değerlendirmeye olanak sağlayan önemli bir kavramsal çerçeve sunmaktadır.

Sosyal hizmet perspektifinde travmatik yas müdahaleleri, yalnızca kayıp sonrasında ortaya çıkan belirtilerin azaltılmasını değil, bireyin uyum kapasitesinin yeniden güçlendirilmesini de hedeflemektedir. Bu kapsamda psikoeğitim, bireysel ve grup temelli yas danışmanlığı, sosyal destek sistemlerinin harekete geçirilmesi, anlam oluşturmayı destekleyen uygulamalar ve terapötik teknikler önemli müdahale araçları olarak değerlendirilmektedir. Mektup yazma, anlatı çalışmaları, sanat temelli uygulamalar, metafor kullanımı, destek grupları ve yeniden anlamlandırmaya yönelik yaklaşımlar, bireyin kaybı yaşam öyküsüne entegre etmesini kolaylaştıran uygulamalar arasında yer almaktadır (Yelboğa, 2023b).

Mikro Düzey

Bireyle çalışma*:* Salutojenik model, mikro düzey sosyal hizmet uygulamalarında travmatik kayıp yaşayan bireyle yürütülen çalışmalara bütüncül bir bakış açısı kazandırmaktadır. Modelin temelini oluşturan bütünlük duygusu bileşenleri olan anlaşılırlık, yönetilebilirlik ve anlamlılık, bireyin kayıp deneyimini değerlendirmede ve müdahale sürecini planlamada önemli bir çerçeve sunmaktadır (Antonovsky, 1997). Bu doğrultuda sosyal hizmet uzmanı, danışanın yaşadığı kaybı nasıl anlamlandırdığını, mevcut baş etme kaynaklarını nasıl kullandığını ve yaşamını yeniden yapılandırmasına katkı sağlayacak motivasyon alanlarını belirleyerek bireye özgü bir müdahale planı geliştirebilir. Böylece bireyle çalışma süreci, yalnızca travmatik belirtilerin ya da yas tepkilerinin değerlendirilmesine odaklanmak yerine, danışanın güçlü yönlerini, dayanıklılık kapasitesini ve iyileşme potansiyelini ortaya çıkarmayı hedefleyen güçlendirme temelli bir nitelik kazanmaktadır. Bu yaklaşım, bireyin yaşadığı kaybı yaşam öyküsü içerisinde yeniden anlamlandırmasını desteklerken, mevcut kişisel ve çevresel kaynaklarını daha etkin kullanmasına da katkı sağlamaktadır.

Yas terapisiyle entegrasyon*:* Salutojenik modelin anlamlılık bileşeni, travmatik kayıp sonrasında bireyin yaşamını yeniden anlamlandırma sürecini destekleyen önemli bir çerçeve sunmaktadır (Kast, 2013). Bu yönüyle model, mikro düzeyde yürütülen yas terapisi uygulamalarıyla bütünleştirilebilir niteliktedir. Yas terapisi sürecinde sosyal hizmet uzmanı, danışanın kayıp deneyimini yaşam öyküsü içerisinde yeniden konumlandırmasına, kayba ilişkin duygularını güvenli bir ortamda ifade etmesine ve geleceğe yönelik yeni anlamlar geliştirmesine eşlik eder (Yelboğa, 2023b). Bu süreçte bireyin varoluşsal sorgulamalarına alan açılması, anlam arayışının yargılanmadan desteklenmesi ve kişinin dini, kültürel ve toplumsal değerlerinin müdahale sürecine duyarlı biçimde dâhil edilmesi önem taşımaktadır. Böylece sosyal hizmet uzmanı yalnızca yas belirtilerinin azaltılmasına odaklanan bir uygulayıcı değil, bireyin yaşamla yeniden bağ kurmasını ve anlam üretme kapasitesini güçlendirmesini destekleyen kolaylaştırıcı bir rol üstlenmektedir. Salutojenik model ile yas terapisinin bütünleştirilmesi, kayıp deneyiminin yalnızca acı veren bir yaşantı olarak değil, bireyin yaşam anlatısında yeniden yapılandırılabilecek bir süreç olarak ele alınmasına katkı sağlamaktadır.

Mezzo Düzey

Destek grupları*:* Salutojenik modelin yönetilebilirlik bileşeni, bireyin yalnızca kişisel baş etme becerilerine değil, aynı zamanda çevresindeki sosyal destek sistemlerini etkili biçimde kullanabilmesine de vurgu yapmaktadır (Wiesmann, 2013). Bu doğrultuda mezzo düzey sosyal hizmet müdahaleleri, travmatik kayıp yaşayan bireylerin aile, akran ve toplumsal destek ağlarıyla yeniden bağlantı kurmalarını destekleyen önemli uygulama alanlarıdır. Özellikle destek grupları, benzer kayıp deneyimlerine sahip bireylerin yaşantılarını paylaşmalarına, yalnızlık duygusunun azalmasına, karşılıklı öğrenme ve duygusal dayanışmanın gelişmesine olanak tanımaktadır. Grup süreci içerisinde bireyler yalnızca destek alan değil, aynı zamanda başkalarına destek sunabilen aktif katılımcılar hâline gelmekte; bu durum ise yönetilebilirlik algısını ve baş etme kapasitesini güçlendirmektedir. Bu bağlamda sosyal hizmet uzmanı, grup süreçlerini kolaylaştıran, sosyal destek ağlarını harekete geçiren ve danışanların toplumsal kaynaklara erişimini güçlendiren bir kolaylaştırıcı ve güçlendirici rol üstlenmektedir. Böylece salutojenik yaklaşım, destek gruplarını yalnızca duygusal paylaşım ortamı olarak değil, bireylerin dayanıklılıklarını ve sosyal kaynaklarını geliştiren önemli bir müdahale aracı olarak değerlendirmektedir.

Akran desteği*:* Salutojenik yaklaşım, iyileşme sürecini yalnızca bireysel baş etme becerileriyle sınırlı görmemekte, sosyal çevrede yer alan destek kaynaklarının etkin biçimde kullanılmasını da önemli bir koruyucu unsur olarak değerlendirmektedir (Maoz, 1998).

Bu doğrultuda akran desteği, travmatik kayıp yaşayan bireylerin benzer deneyimlere sahip kişilerle güvene dayalı ilişkiler kurmalarına, yaşantılarını paylaşmalarına ve karşılıklı destek geliştirmelerine olanak tanıyan önemli bir mezzo düzey sosyal hizmet müdahalesidir. Akran gruplarında bireyler, kayıp deneyiminin oluşturduğu yalnızlık ve çaresizlik duygularını azaltırken, baş etme stratejileri konusunda birbirlerinden öğrenme fırsatı da bulmaktadır. Bu süreç, bireyin sosyal destek algısını güçlendirmekte, mevcut kaynaklarını daha etkin kullanmasına katkı sağlamakta ve yönetilebilirlik duygusunu desteklemektedir. Sosyal hizmet uzmanı ise akran destek mekanizmalarının oluşturulması, grup üyeleri arasındaki etkileşimin kolaylaştırılması ve bu destek ağlarının sürdürülebilirliğinin sağlanmasında koordinatör ve güçlendirici bir rol üstlenmektedir. Böylece akran desteği, travmatik kayıp sonrası iyileşmeyi destekleyen ve bireyin toplumsal bağlarını yeniden güçlendiren önemli bir sosyal hizmet uygulaması olarak öne çıkmaktadır.

Makro Düzey

Afet sonrası psikososyal çalışmalar: Salutojenik modelin afet sonrası müdahalelerde kullanıldığı çalışmalar bu yaklaşımın dayanıklılığı artırmaktan destek sistemlerinin devreye sokulmasına kadar geniş bir yelpazede uygulamaya katkı sunduğunu göstermiştir (Mittelmark vd., 2022). Bu anlamda modelin temelini oluşturan ***anlaşılırlık***, ***yönetilebilirlik*** ve ***anlamlılık*** bileşenleri, afet sonrasında yürütülen psikososyal sosyal hizmet uygulamalarında önemli işlevler üstlenebilir. Afetin neden olduğu belirsizliğin azaltılması ve bireylerin yaşadıkları süreci anlamlandırmalarına destek olunması anlaşılırlık duygusunu güçlendirirken; aile, akran ve toplum temelli destek sistemlerinin yeniden örgütlenmesi ile hizmet ve kaynaklara erişimin kolaylaştırılması yönetilebilirlik duygusunu desteklemektedir. Bunun yanında bireylerin kayıp deneyimini yaşam öykülerinin bir parçası hâline getirebilmelerine ve yaşamla yeniden bağ kurabilmelerine yönelik müdahaleler ise anlamlılık duygusunun yeniden inşasına katkı sağlayabilir.

Toplum dayanıklılığı: Salutojenik model, makro düzey sosyal hizmet uygulamalarında travmatik kayıp ve yasın yalnızca bireysel bir deneyim olarak değil, toplumsal düzeyde ele alınması gereken bir süreç olduğunu ortaya koymaktadır. Özellikle sosyal dışlanma, zorunlu göç, afetler ve kitlesel kayıplar sonrasında yürütülen sosyal hizmet uygulamalarında, bireylerin ve toplulukların mevcut baş etme kaynaklarının güçlendirilmesi, sosyal destek sistemlerinin yeniden yapılandırılması ve toplumsal dayanışmanın artırılması önem kazanmaktadır. Bu doğrultuda göçmen kadınlarla yürütülen salutojenik temelli sosyal hizmet uygulamalarının, bireylerin kendi direnç kaynaklarını fark etmelerine ve yaşadıkları güçlüklerle daha etkili biçimde baş etmelerine katkı sağladığı gösterilmiştir (Bonmatí-Tomas vd., 2019). Elde edilen bulgular, salutojenik yaklaşımın yapısal eşitsizlikler ve sosyal dışlanma nedeniyle zayıflayan baş etme kapasitesini güçlendirmede işlevsel bir çerçeve sunduğunu ortaya koymaktadır. Ayrıca bu yaklaşım, bireyleri yalnızca travmanın olumsuz sonuçları üzerinden değerlendiren patoloji odaklı bakışın ötesine geçerek, travmatik yaşantılara rağmen varlığını sürdüren kişisel ve toplumsal kaynakları görünür kılmaktadır (Bonmatí-Tomas vd., 2019; Mittelmark vd., 2022). Bu yönüyle salutojenik model, travmatik kayıp ve yas alanında toplum temelli sosyal hizmet programlarının geliştirilmesi, afet sonrası psikososyal destek sistemlerinin güçlendirilmesi ve toplumsal dayanıklılığı artırmaya yönelik sosyal politikaların oluşturulmasına katkı sağlayabilecek önemli bir yaklaşım olarak değerlendirilebilir.

Yukarıdaki örneklerden görüldüğü üzere salutojenik modelin temel bileşenleri, sosyal hizmet müdahalelerinin farklı düzeylerinde uygulanabilecek önemli bir çerçeve sunmaktadır. Mikro düzeyde bireyin kaybı anlamlandırması, güçlü yönlerini fark etmesi ve baş etme becerilerinin geliştirilmesi ön plana çıkarken mezzo düzeyde sosyal destek ağlarının güçlendirilmesi ve akran desteği gibi müdahaleler önem kazanmaktadır. Makro düzeyde ise toplum temelli yas hizmetleri, afet sonrası psikososyal destek sistemleri ve toplum dayanıklılığını artırmaya yönelik sosyal politikalar, salutojenik yaklaşımın temel ilkelerini uygulamaya yansıtan müdahale alanları olarak değerlendirilebilir.

Bu örnekler doğrultusunda aşağıda (Tablo 2) salutojenik modelin kayıp ve yas sürecine kavramsal katkıları ortaya çıkmaktadır.

Tablo 2. Salutojenik Modelin Kayıp ve Yas Sürecine Kavramsal Katkıları

Kavramsal Açılım	Kayıp ve Yas Sürecindeki Katkısı	Sosyal Hizmet Açısından Yansıması
Yas sürecini patolojiden sağlığa taşımak	Yasın yalnızca belirtiler ve riskler üzerinden değil, bireyin uyum ve iyileşme kapasitesi üzerinden değerlendirilmesini sağlar.	Güçlendirme odaklı değerlendirme, iyilik hâlinin desteklenmesi ve koruyucu müdahalelerin planlanması.
Güçlü yön perspektifini desteklemek	Kayıp yaşayan bireyin yalnızca yaşadığı sorunları değil, sahip olduğu güçlü yönleri ve baş etme kapasitesini görünür kılar.	Güçler perspektifine dayalı değerlendirme, danışanın aktif katılımının teşvik edilmesi ve öz yeterliliğin artırılması.
Anlam inşasını kolaylaştırmak	Kayıp deneyiminin yaşam öyküsü içinde yeniden anlamlandırılmasını ve yaşam amaçlarının yeniden oluşturulmasını destekler.	Anlatı çalışmaları, yaşam öyküsü yaklaşımı, anlam odaklı görüşmeler ve yas danışmanlığı uygulamaları.
Sosyal destek ağlarını güçlendirmek	İyileşme sürecinde aile, arkadaş, topluluk ve profesyonel destek sistemlerinin önemini vurgular.	Sosyal destek ağlarının mobilizasyonu, grup çalışmaları, akran desteği ve toplum temelli müdahaleler.
Dayanıklılık ve uyumu desteklemek	Travmatik kayba rağmen bireyin yeni yaşam koşullarına uyum geliştirme ve psikolojik dayanıklılığını artırma sürecini açıklar.	Dayanıklılığı artıran müdahaleler, kriz sonrası güçlendirme, afet ve travma sosyal hizmeti uygulamaları.
Bireysel kaynakları görünür kılmak	Bireyin sahip olduğu kişisel, sosyal, kültürel ve çevresel kaynakların fark edilmesini ve etkin kullanılmasını teşvik eder.	Kaynak değerlendirmesi, hizmetlere erişimin kolaylaştırılması, savunuculuk ve vaka yönetimi uygulamaları.

Tartışma

Bu çalışma kayıp travmasını yas ve psikolojik travma yaklaşımlarının kesişiminde ele alarak salutojenik modelin travmatik kayıp sonrasında bireylerin uyum ve dayanıklılık süreçlerine sağlayabileceği katkıları tartışmaktadır. Söz konusu tartışma, modelin sosyal hizmetin kayıp ve yas alanındaki uygulamalarına yönelik potansiyel katkılarını kavramsal bir çerçevede değerlendirme ve sosyal hizmet literatürüne ve uygulamalarına yeni açılımlar sunma şeklinde gerçekleştirilmiştir. Buna göre bu çalışmanın temel bulgularından biri, salutojenik yaklaşımın travmatik kayıp ve yas sürecinin değerlendirilmesinde sosyal hizmetin güçlendirme odaklı bakış açısıyla önemli ölçüde örtüştüğünü göstermesidir. Geleneksel patojenik yaklaşımlar, çoğunlukla yasın komplikasyonları ve psikopatolojik belirtiler üzerinde yoğunlaşırken salutojenik model bireyin sahip olduğu güçlü yönlere, baş etme kapasitesine ve iyileşme potansiyeline odaklanmaktadır (Antonovsky, 1997). Bu yönüyle model, sosyal hizmetin bireyin güçlü yanlarını ortaya çıkarmayı ve çevresel kaynakları harekete geçirmeyi esas alan uygulama anlayışıyla uyumlu bir kavramsal zemin sunmaktadır.

Çalışmada önerilen kavramsal çerçeve, salutojenik modelin üç temel bileşeninin sosyal hizmet müdahaleleriyle doğrudan ilişkilendirilebileceğini ortaya koymaktadır. Yönetilebilirlik bileşeni, danışanın kişisel ve çevresel kaynaklarının güçlendirilmesi, sosyal destek sistemlerine erişimin kolaylaştırılması ve baş etme becerilerinin geliştirilmesine yönelik uygulamalarla örtüşmektedir. Anlaşılırlık bileşeni, bireyin travmatik kayıp deneyimini anlamlandırmasını destekleyen psikoeğitim, psikososyal değerlendirme ve farkındalık odaklı müdahaleler için açıklayıcı bir çerçeve sunmaktadır. Anlamlılık bileşeni ise bireyin yaşam öyküsünü yeniden yapılandırmasına, kaybı yaşam deneyiminin bir parçası hâline getirmesine ve geleceğe ilişkin umut geliştirmesine katkı sağlayan müdahaleleri desteklemektedir. Bu değerlendirme, salutojenik modelin sosyal hizmet uygulamalarının mikro, mezzo ve makro düzeylerinde kullanılabilecek işlevsel bir yaklaşım olduğunu göstermektedir.

Bu bulgular, travmatik yas alanında sosyal hizmet müdahalelerinin semptomların azaltılması dışında bireyin dayanıklılığının, sosyal kaynaklarının ve yaşamı yeniden anlamlandırma kapasitesinin güçlendirilmesine odaklanması gerektiğini vurgulayan çalışmalarla da paralellik göstermektedir (Yelboğab, 2023; Wiesmann, 2013). Özellikle sosyal destek ağlarının güçlendirilmesi, bireyin karar verme süreçlerine aktif katılımının desteklenmesi ve anlam oluşturma süreçlerinin teşvik edilmesi, salutojenik yaklaşımın sosyal hizmet uygulamalarına sağlayabileceği önemli katkılar arasında yer almaktadır. Bu çerçevede salutojenik model, travmatik kayıp yaşayan bireylerle çalışan sosyal hizmet uzmanlarına yalnızca risk ve sorunları değerlendiren bir bakış açısı değil, aynı zamanda danışanın mevcut kaynaklarını görünür kılan, dayanıklılığını destekleyen ve iyileşme sürecini güçlendiren bütüncül bir müdahale perspektifi sunmaktadır. Dolayısıyla modelin sosyal hizmet uygulamalarına entegrasyonu, travmatik kayıp ve yas alanında daha güçlendirme temelli, kaynak odaklı ve sürdürülebilir müdahale yaklaşımlarının geliştirilmesine katkı sağlayabilecek önemli bir açılım olarak değerlendirilebilir.

Salutojenik modelin literatüre en önemli katkılarının bireyin güçlü yönlerini, baş etme becerilerini, sosyal destek ağlarını ve yaşamın yeniden anlamlandırılmasını desteklemeye odaklanmaktadır. Bu yönüyle söz konusu katkılar sosyal hizmet müdahalelerinde güçlendirme yaklaşımıyla salutojenik modelin temel bileşenleri olan anlaşılırlık, yönetilebilirlik ve anlamlılık ile büyük ölçüde örtüşmektedir. Dolayısıyla salutojenik model, travmatik yas alanında kullanılan psikososyal müdahaleleri bütüncül bir çerçevede açıklayan ve sosyal hizmet uygulamalarını güçlendiren önemli bir kavramsal yaklaşım olarak değerlendirilebilir.

Sonuç

Bu çalışma, ani ve beklenmedik ölümler sonrasında ortaya çıkan travmatik kaybı, yas ve psikolojik travma yaklaşımlarını bir araya getiren bütüncül bir bakış açısıyla ele almış ve bu süreci Antonovsky'nin salutojenik modeli doğrultusunda yeniden değerlendirmiştir. Bulgular, travmatik kaybın yalnızca sevilen bir kişinin yitirilmesine bağlı duygusal acıyı değil, aynı zamanda bireyin güvenlik algısını, benlik bütünlüğünü ve yaşamın anlamına ilişkin temel varsayımlarını sarsan çok boyutlu bir deneyim olduğunu ortaya koymaktadır. Bu nedenle travmatik kaybın yalnızca yas ya da yalnızca travma perspektifiyle açıklanması yeterli olmayıp, her iki yaklaşımın birlikte değerlendirilmesini gerektiren kapsamlı bir çerçeveye ihtiyaç duyulmaktadır.

Salutojenik model, travmatik kayıp sonrasında bireylerin yaşadıkları güçlüklere ek olarak aynı zamanda sahip oldukları koruyucu kaynakları, dayanıklılıklarını ve iyileşme potansiyellerini görünür kılan bir yaklaşım sunmaktadır. Modelin temel bileşenleri olan anlaşılırlık, yönetilebilirlik ve anlamlılık; bireyin yaşadığı kaybı anlamlandırmasını, kişisel ve çevresel kaynaklarını harekete geçirmesini ve yaşamla yeniden bağ kurmasını destekleyen temel süreçler olarak öne çıkmaktadır. Böylece travmatik kayıp, yalnızca psikopatolojik belirtiler üzerinden değil, bireyin uyum kapasitesi ve güçlenme olanakları üzerinden de değerlendirilebilmektedir.

Sosyal hizmet açısından değerlendirildiğinde salutojenik model, güçlendirme yaklaşımı, ekolojik bakış açısı ve kişi-çevre etkileşimini (çevresi içinde birey) temel alan mesleki uygulamalarla önemli ölçüde örtüşmektedir. Model, mikro düzeyde bireyin baş etme kapasitesinin desteklenmesine, mezzo düzeyde sosyal destek sistemlerinin ve grup çalışmalarının güçlendirilmesine, makro düzeyde ise toplum temelli yas hizmetleri, afet sonrası psikososyal müdahaleler ve toplum dayanıklılığını geliştirmeye yönelik politikaların şekillendirilmesine katkı sağlayabilecek kavramsal bir çerçeve sunmaktadır. Bu yönüyle salutojenik yaklaşım, travmatik kayıp yaşayan bireylerle yürütülen sosyal hizmet uygulamalarına yalnızca sorun odaklı değil, aynı zamanda kaynak ve güç odaklı bir perspektif kazandırmaktadır.

Türkiye'de yas, travma ve sosyal hizmet alanlarında yürütülen çalışmalar giderek artmakla birlikte travmatik kaybın salutojenik model ekseninde değerlendirilmesine yönelik kuramsal çalışmaların sınırlı olduğu görülmektedir. Bu çalışma, söz konusu boşluğu doldurmayı amaçlayarak salutojenik yaklaşımın travmatik kayıp alanındaki açıklayıcılığını ortaya koymakta ve sosyal hizmet uygulamaları açısından kullanılabilecek kavramsal bir çerçeve önermektedir. Özellikle modelin sosyal hizmetin mikro, mezzo ve makro müdahale düzeyleriyle ilişkilendirilmesi, çalışmanın özgün katkılarından biri olarak değerlendirilebilir.

Gelecekte gerçekleştirilecek araştırmalarda salutojenik modelin travmatik kayıp yaşayan çocuklar, yaşlılar, afet mağdurları, zorunlu göç deneyimi yaşayan bireyler ve farklı kırılgan gruplar üzerindeki uygulanabilirliğinin ampirik çalışmalarla test edilmesi önem taşımaktadır. Ayrıca Türkiye'de travmatik kayıp ve yas alanında sosyal hizmet odaklı nitel ve nicel saha araştırmalarının artırılması hem kuramsal bilgi birikiminin gelişmesine hem de kanıta dayalı müdahale modellerinin oluşturulmasına katkı sağlayacaktır.

Bu çalışma doğrultusunda aşağıdaki öneriler sunulabilir:

- Travmatik kayıp yaşayan bireylerle yürütülen sosyal hizmet uygulamalarında, yalnızca risk ve psikopatolojik belirtilere değil, bireyin güçlü yönleri, baş etme kapasitesi ve mevcut direnç kaynaklarına odaklanan salutojenik bir değerlendirme yaklaşımı benimsenmelidir.
- Mikro, mezzo ve makro düzey sosyal hizmet müdahalelerinde salutojenik modelin temel bileşenleri olan anlaşılırlık, yönetilebilirlik ve anlamlılık doğrultusunda psikososyal müdahaleler, destek grupları ve toplum temelli uygulamalar geliştirilmelidir.
- Afetler, kitlesel kayıplar ve zorunlu göç gibi travmatik kayıpların yoğun yaşandığı durumlarda hazırlanacak psikososyal destek programları ve sosyal politika çalışmalarında salutojenik yaklaşımın sunduğu koruyucu ve güçlendirici bakış açısından yararlanılması önerilmektedir.
- Sosyal hizmet eğitiminde travmatik kayıp, yas danışmanlığı ve salutojenik modele daha fazla yer verilerek, uygulayıcıların bu alandaki kuramsal bilgi ve müdahale becerileri desteklenmelidir.
- Gelecekte yapılacak araştırmalarda salutojenik modele dayalı sosyal hizmet müdahalelerinin etkililiği farklı örneklem gruplarında ampirik araştırmalarla değerlendirilerek modelin uygulamadaki geçerliliğine ilişkin kanıtlar güçlendirilmelidir.

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2023 DEPREMLERİ SONRASINDA TÜRKİYE'DE TARIM ARAZİSİ FİYATLARINDAKİ REEL DEĞİŞİM: DÖRT İLİN KARŞILAŞTIRMALI ANALİZİ[40]

REAL CHANGES IN AGRICULTURAL LAND PRICES AFTER THE 2023 EARTHQUAKES IN TÜRKIYE: A COMPARATIVE ANALYSIS OF FOUR PROVINCES[1]

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ÖZET

Bu çalışma, 6 Şubat 2023 depremleri sonrasında Adıyaman, Hatay, Kahramanmaraş ve Malatya illerindeki tarım arazisi fiyatlarında gözlenen değişimleri nominal ve enflasyondan arındırılmış reel değerler üzerinden incelemeyi amaçlamaktadır. Araştırmanın verileri 274 tarımsal üretici, 665 hane halkı ve 108 uzmandan elde edilmiş; gruplar farklı örneklem çerçevelerini temsil ettiğinden ayrı ayrı analiz edilmiştir. Sulu tarla, kuru tarla ve bahçe fiyatlarının Aralık 2022 ile Haziran 2024 dönemleri arasındaki değişimi Wilcoxon İşaretli Sıralar Testiyle, veri yapısının izin verdiği il karşılaştırmaları ise Kruskal-Wallis testiyle değerlendirilmiştir. Nominal fiyatlar, aynı dönemde TÜFE'de gerçekleşen %105,53'lük artış esas alınarak reel değerlere dönüştürülmüştür. Üç veri kaynağında da deprem sonrası nominal fiyatların istatistiksel olarak anlamlı biçimde arttığı belirlenmiştir ($p<0,0001$). Üretici verilerinde sulu tarla, kuru tarla ve bahçe fiyatlarındaki nominal artışlar sırasıyla %163,28, %123,78 ve %174,02; reel artışlar ise %28,10, %8,88 ve %33,32 olarak hesaplanmıştır. Hane halkı verilerinde en yüksek reel artış sulu tarlada %54,75, uzman verilerinde ise yine sulu tarlada %21,36 olarak hesaplanmıştır. Uzmanların kuru tarla değerlendirmesi %5,02 reel azalış göstermiştir. Uzmanların kuru tarla değerlendirmesinde %5,02 reel azalış saptanmıştır.

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Arsa fiyatlarına ilişkin hane halkı değerlendirmesi %64,39 reel artışa, uzman değerlendirmesi ise %6,99 reel azalışa işaret etmiştir. Bazı göstergelerin illere göre farklılaşması, piyasa hareketlerinin mekânsal olarak homojen olmadığını göstermektedir. Araştırmanın gözlemsel ve geriye dönük yapısı nedeniyle bulgular, depremlerin nedensel etkisini değil, deprem sonrası dönemde gözlenen fiyat değişimlerini ortaya koymaktadır. Sonuçlar, afet sonrası arazi piyasalarının nominal ve reel göstergeler, arazi türleri, veri kaynakları ve mekânsal farklılıklar birlikte dikkate alınarak izlenmesi gerektiğini göstermektedir.
Anahtar Kelimeler: 2023 depremleri, tarım arazisi, arazi fiyatları, reel fiyat değişimi, kırsal arazi piyasası, afet sonrası toparlanma, Türkiye.

ABSTRACT
This study examines nominal and inflation-adjusted changes in agricultural land prices following the earthquakes of 6 February 2023 in Adıyaman, Hatay, Kahramanmaraş, and Malatya provinces of Türkiye. Data were obtained from 274 agricultural producers, 665 households, and 108 experts. Because these groups represented different sampling frames, each was analysed separately. Changes in irrigated cropland, dry cropland, and orchard prices between December 2022 and June 2024 were evaluated using the Wilcoxon signed-rank test, while provincial comparisons permitted by the data structure were assessed using the Kruskal-Wallis test. Nominal prices were converted into real terms based on the 105.53% increase in the Consumer Price Index over the same period. Post-earthquake nominal prices increased significantly across all three data sources ($p<0.0001$). Producer-reported nominal increases for irrigated cropland, dry cropland, and orchards were 163.28%, 123.78%, and 174.02%, respectively, while the corresponding real increases were 28.10%, 8.88%, and 33.32%. The highest real increase was 54.75% for irrigated cropland in household assessments and 21.36% for irrigated cropland in expert assessments. Experts reported a 5.02% real decrease for dry cropland. For residential plots, household assessments indicated a 64.39% real increase, while expert assessments indicated a 6.99% real decrease. Provincial differences in selected indicators show that post-disaster market movements were spatially heterogeneous. Because the study used an observational and retrospective design, the findings describe price changes observed after the earthquakes rather than their causal effects. The results demonstrate the need to monitor post-disaster land markets by jointly considering nominal and real indicators, land categories, data sources, and spatial variation.
Keywords: 2023 earthquakes, agricultural land, land prices, real price change, rural land market, post-disaster recovery, Türkiye.

GİRİŞ

Araştırma problemi ve bağlam

Tarım arazisi, tarımsal üretimin temel girdilerinden biri olmasının yanında kırsal hanelerin servet birikimini, yatırım kapasitesini ve üretimin sürekliliğini etkileyen bir varlıktır. Hedonik fiyat yaklaşımına göre arazi fiyatı, taşınmazın farklı özelliklerinin piyasada birlikte değerlenmesinin sonucudur (Rosen, 1974). Tarımsal getiri, faiz, enflasyon ve beklentiler de arazi fiyatlarının zaman içindeki değişimini etkileyebilmektedir (Just ve Miranowski, 1993; Goodwin vd., 2003).

Büyük ölçekli doğal afetler; fiziksel hasar, nüfus hareketleri, yeniden yapılanma, yatırım beklentileri, arazi kullanımı ve risk algısı üzerinden arazi piyasalarını etkileyebilir. Bu kanallar aynı yönde çalışmadığından afet sonrasında fiyatların mutlaka düşmesi veya yükselmesi beklenemez. Fiziksel zarar ve artan risk algısı aşağı yönlü; yeniden yapılanma talebi, alternatif kullanım beklentisi ve kısa dönemde sınırlı arazi arzı yukarı yönlü baskı oluşturabilir.

6 Şubat 2023 depremleri, deprem bölgesindeki kırsal yerleşimleri, tarımsal üretim altyapısını, sulama, depolama, hayvancılık ve lojistik sistemlerini önemli ölçüde etkilemiştir. Ulusal hasar değerlendirmeleri ile FAO'nun müdahale ve iyileştirme planı, tarımsal üretimin sürekliliği, girdi erişimi ve kırsal altyapının onarımını temel gereksinimler arasında göstermektedir (SBB, 2023; FAO, 2023). Bu koşullar, tarımsal üretim kadar arazi piyasasındaki değer hareketlerinin de izlenmesini gerekli kılmaktadır.

Tarım arazisi fiyatlarının belirleyicileri

Arazi değeri; toprak niteliği, sulama olanakları, parsel büyüklüğü ve topografya gibi üretimsel özelliklerin yanı sıra konum, çevresel olanaklar, ulaşılabilirlik, kentleşme baskısı ve alternatif kullanım beklentileriyle şekillenmektedir (Maddison, 2000; Bastian vd., 2002; Plantinga vd., 2002). Dolayısıyla

arazi fiyatı yalnızca mevcut tarımsal gelir akımını değil, gelecekteki gelir ve kullanım beklentilerini de yansıtmaktadır.
Farklı ülke ve bölgelerde yapılan araştırmalar, üretkenlik, parsel büyüklüğü, kentsel merkezlere uzaklık, mekânsal bağımlılık ve tarım dışı kullanım değerinin fiyatlarda belirleyici olduğunu göstermektedir (Huang vd., 2006; Tsoodle vd., 2006; Kostov, 2009; Borchers vd., 2014). Sistematik literatür incelemesi de fiziksel, ekonomik, çevresel ve mekânsal değişkenlerin birlikte değerlendirilmesi gerektiğini vurgulamaktadır (Tavares vd., 2022).

Afetler ve arazi piyasaları
Deprem riskinin piyasa değerlerine yansıdığı erken dönem çalışmalardan itibaren risk algısı, afet deneyimi ve bilginin görünürlüğünün gayrimenkul fiyatlarını değiştirebildiği gösterilmiştir (Brookshire vd., 1985; Beron vd., 1997). Japonya'daki çalışmalar, deprem riski yüksek alanlarda fiyat iskontosu bulunabildiğini ve büyük depremlerden sonra risk değerlendirmelerinin değişebildiğini ortaya koymaktadır (Nakagawa vd., 2009; Naoi vd., 2009; Gu vd., 2018).
Fiziksel hasar ve afetle ilişkilendirilen damgalanma değerleri azaltabilirken yeniden yapılanma, kısıtlı arazi arzı ve alternatif kullanım beklentileri ters yönde baskı oluşturabilir (Messer vd., 2006). Tarımsal afet yardımlarıyla arazi fiyatları arasındaki ilişkiyi işlem verileri üzerinden inceleyen çalışma da desteklerin kapitalizasyon etkisinin afet kaynaklı damgalanma tarafından dengelenebileceğini göstermektedir (Lee vd., 2021). Bu bulgular, afet sonrası tarım arazisi piyasasında tek yönlü bir fiyat tepkisi varsayılmaması gerektiğine işaret etmektedir.

Nominal ve reel fiyat ayrımı
Deprem sonrası dönem yüksek enflasyon koşullarıyla çakıştığından, nominal artışların doğrudan ekonomik değer kazancı olarak yorumlanması yanıltıcı olabilir. Farklı dönemlerdeki parasal değerlerin karşılaştırılmasında uygun bir fiyat endeksiyle deflasyon yapılması, uluslararası tüketici fiyat endeksi yöntemlerinin temel uygulamalarındandır (ILO vd., 2020). Bu çalışmada nominal değişimlerin yanı sıra genel tüketici fiyat düzeyine göre reel değişim de hesaplanmıştır.

Afet sonrası arazi fiyatlarını etkileyebilecek mekanizmalar
Afet sonrası arazi piyasasına ilişkin ilk mekanizma fiziksel hasar ve üretim kapasitesidir. Sulama şebekeleri, tarla yolları, depolama alanları, hayvancılık tesisleri ve diğer kırsal altyapı unsurlarındaki bozulma, araziden beklenen gelir akımını ve üretimin sürdürülebilirliğini olumsuz etkileyebilir. Varlık fiyatlandırma yaklaşımında gelecekte beklenen net getirilerin azalması, diğer koşullar sabitken arazi değerini aşağı çekebilecek bir unsurdur (Just ve Miranowski, 1993; Goodwin vd., 2003). Bununla birlikte onarımın hızlı gerçekleşmesi veya üretim kapasitesinin korunması hâlinde aynı mekanizmanın etkisi sınırlı kalabilir.
İkinci mekanizma risk algısıdır. Büyük bir afet, daha önce örtük kalan sismik risk bilgisini görünür kılarak alıcıların ödeme isteğini ve satıcıların beklentilerini değiştirebilir. Deprem riskinin arazi ve konut fiyatlarına yansıdığına ilişkin çalışmalar, risk bilgisinin ve afet deneyiminin piyasa değerlerinde iskonto oluşturabildiğini göstermektedir (Brookshire vd., 1985; Beron vd., 1997; Nakagawa vd., 2009; Naoi vd., 2009). Ancak bu kanala ilişkin bulguların önemli bir kısmı kentsel gayrimenkul piyasalarına dayandığından tarım arazilerine doğrudan aktarılması ihtiyat gerektirir.
Üçüncü mekanizma yeniden yapılanma ve değişen arazi talebidir. Yerleşim alanlarının yeniden düzenlenmesi, geçici veya kalıcı barınma gereksinimi, yeni altyapı yatırımları ve güvenli kabul edilen alanlara yönelim, belirli bölgelerde arazi talebini artırabilir. Tarım dışı kullanım beklentilerinin arazi değerine kapitalizasyonu, tarımsal getirinin ötesinde bir fiyat bileşeni yaratabilmektedir (Plantinga vd., 2002; Borchers vd., 2014). Bu nedenle afet sonrasında bazı arazilerde üretim kaybıyla eş zamanlı olarak alternatif kullanım beklentisine bağlı yukarı yönlü baskı görülebilir.
Dördüncü mekanizma, arazi arzının kısa dönemde esnek olmamasıdır. Belirli konum ve nitelikteki arazi miktarı kısa sürede artırılamadığından talepteki sınırlı bir artış dahi fiyatlara güçlü biçimde yansıyabilir. Konum, erişilebilirlik ve mekânsal bağımlılığın arazi fiyatlarında önemli olması da bu sınırlılığı güçlendirmektedir (Bastian vd., 2002; Tsoodle vd., 2006; Kostov, 2009). Bu dört mekanizma çalışmanın bulgularını yorumlamak için kuramsal bir çerçeve sunmaktadır; mevcut veri setinde hasar, risk algısı, yeniden yapılanma talebi veya arz esnekliği doğrudan ölçülmediği için mekanizmaların hiçbiri ampirik olarak sınanmamıştır.

Literatürdeki boşluk ve çalışmanın katkısı

İlgili literatür üç ana çizgide gelişmektedir. Birinci çizgi; üretkenlik, sulama, parsel büyüklüğü, konum ve tarım dışı kullanım beklentileri gibi tarım arazisi fiyatı belirleyicilerine odaklanmaktadır (Maddison, 2000; Bastian vd., 2002; Huang vd., 2006; Tavares vd., 2022). İkinci çizgi, deprem riskinin özellikle konut ve kentsel arazi değerlerine kapitalizasyonunu incelemektedir (Nakagawa vd., 2009; Naoi vd., 2009; Gu vd., 2018). Üçüncü çizgi ise 2023 depremlerinin tarımsal üretim, kırsal altyapı ve toparlanma gereksinimleri üzerindeki etkilerini belgeleyen kurumsal değerlendirmelerden oluşmaktadır (SBB, 2023; FAO, 2023).

Bu üç alan birlikte değerlendirildiğinde, 6 Şubat 2023 depremleri sonrasında tarım arazisi fiyatlarını farklı piyasa aktörleri üzerinden ve nominal-reel ayrımıyla karşılaştıran ampirik kanıtın sınırlı olduğu görülmektedir. Çalışma bu boşluğa dört yönden katkı sunmaktadır: Adıyaman, Hatay, Kahramanmaraş ve Malatya'yı aynı analiz çerçevesinde ele almakta; üretici, hane halkı ve uzman verilerini ayrı örneklemler olarak değerlendirmekte; nominal artışları TÜFE ile reel değişime dönüştürmekte ve mevcut verinin elverdiği göstergelerde mekânsal farklılaşmayı sınamaktadır. Bu katkılar, nedensel bir deprem etkisi ölçmekten çok afet sonrası piyasa görünümünü çok kaynaklı ve karşılaştırılabilir biçimde betimlemeye yöneliktir.

Araştırmanın amacı ve soruları

Çalışmanın amacı, 6 Şubat 2023 depremleri sonrasında Adıyaman, Hatay, Kahramanmaraş ve Malatya'da sulu tarla, kuru tarla ve bahçe fiyatlarında gözlenen değişimleri üretici, hane halkı ve uzman verileri üzerinden nominal ve reel olarak belirlemek; mevcut verinin izin verdiği ölçüde iller arasındaki farklılıkları ortaya koymaktır. Araştırma nedensel bir deprem etkisi tahmin etmemekte, deprem öncesi ve sonrası dönemlerde gözlenen fiyat farklılıklarını betimlemektedir.

- Araştırma Sorusu 1: Deprem sonrası dönemde tarım arazisi fiyatlarında istatistiksel olarak anlamlı bir değişim gözlenmiş midir?
- Araştırma Sorusu 2: Nominal fiyat değişimleri enflasyondan arındırıldığında reel değişimler aynı yönde devam etmekte midir?
- Araştırma Sorusu 3: Fiyat değişimleri arazi türüne ve veri kaynağına göre farklılaşmakta mıdır?
- Araştırma Sorusu 4: Mevcut verinin izin verdiği karşılaştırmalarda dört il arasında anlamlı farklılıklar bulunmakta mıdır?

ARAŞTIRMA VE BULGULAR

Araştırma tasarımı ve analitik çerçeve

Araştırma, kesitsel saha verisinden hareketle iki döneme ilişkin fiyatların karşılaştırıldığı gözlemsel ve geriye dönük bir tasarıma sahiptir. Analitik süreç üç aşamada yürütülmüştür. İlk aşamada örneklemlerin yapısı, arazi türleri ve dönem fiyatları betimlenmiştir. İkinci aşamada aynı katılımcıya ait deprem öncesi ve sonrası değerlerin sıralı farkları incelenmiş; üçüncü aşamada nominal değişimler genel tüketici fiyat düzeyine göre reel değişime dönüştürülmüş ve mevcut göstergelerde iller arası farklılıklar sınanmıştır.

Üretici, hane halkı ve uzman grupları aynı evrenden çekilmiş tekrarlı alt örneklemler değildir. Üreticiler araziyi üretim sürecinde kullanan aktörlerin, hane halkları yerel piyasa ve servet değerlendirmelerinin, uzmanlar ise mesleki bilgiye dayalı piyasa görüşlerinin temsilcileri olarak ele alınmıştır. Bu nedenle gruplar arasında doğrudan bir ortalama fark testi yapılmamış, her grubun dönem karşılaştırması kendi veri yapısı içinde değerlendirilmiştir. Gruplar arası benzerlikler yalnızca sonuçların yönü ve büyüklüğü bakımından betimsel olarak karşılaştırılmıştır.

Araştırma alanı ve veri kaynakları

Araştırma alanını 6 Şubat 2023 depremlerinden yoğun biçimde etkilenen Adıyaman, Hatay, Kahramanmaraş ve Malatya illeri oluşturmaktadır. Analizlerde 274 tarımsal üretici, 665 hane halkı ve 108 uzmandan elde edilen saha verileri kullanılmıştır. Üretici grubu araziyi doğrudan tarımsal üretimde kullanan katılımcıları, hane halkı grubu hane düzeyindeki piyasa değerlendirmelerini, uzman grubu ise arazi piyasasına ilişkin bilgi ve deneyime sahip katılımcıların görüşlerini temsil etmektedir. Üç grup farklı örneklem çerçevelerinden geldiğinden sonuçlar birleştirilmemiştir.

Tablo 1. Örneklem büyüklüğü ve illere göre dağılımı

İl	Üretici		Hane halkı		Uzman	
	n	%	n	%	n	%
Adıyaman	44	16,06	122	18,35	22	20,37
Hatay	48	17,52	131	19,70	11	10,19
Kahramanmaraş	90	32,85	232	34,89	64	59,26
Malatya	92	33,57	180	27,06	11	10,19
Toplam	**274**	**100,00**	**665**	**100,00**	**108**	**100,00**

Üretici örnekleminde öngörülen 271 katılımcının üzerinde 274 kişiye, hane halkı örnekleminde hedeflenen 665 kişinin tamamına, uzman grubunda ise hedeflenen 80 kişinin üzerinde 108 katılımcıya ulaşılmıştır. Uzmanların %59,26'sının Kahramanmaraş'tan gelmesi nedeniyle uzman verilerinin il bazındaki yorumunda dağılım dengesizliği dikkate alınmalıdır.

Örneklem gerçekleşme düzeyi

Hedeflenen ve gerçekleşen örneklem büyüklükleri karşılaştırıldığında üretici grubunda %101,11, hane halkı grubunda %100,00 ve uzman grubunda %135,00 gerçekleşme oranına ulaşılmıştır. Hedefin aşılması, özellikle uzman grubunda planlanandan daha fazla katılımcıya erişildiğini göstermektedir; ancak kaynak dokümanda bu aşımın saha uygulamasındaki nedeni açıklanmadığından, seçilme olasılığı veya temsiliyet bakımından ek bir çıkarım yapılmamıştır. İl dağılımının gruplar arasında farklı olması da üç veri kaynağının tek bir birleşik örneklem gibi ele alınmamasının bir diğer gerekçesidir.

Katılımcıların tanımlayıcı özellikleri

Üretici örneklemi hane halkı örnekleminden daha ileri yaşta ve daha düşük eğitim süresine sahiptir. Üreticilerde toplam arazi varlığının yüksek standart sapması, işletme büyüklüklerinin heterojen olduğunu göstermektedir. Uzman grubunda yaş, eğitim ve cinsiyet bilgileri raporlanmamıştır. Kaynak veride uzmanların mülk arazi varlığı 51,26 ± 145,90 da olarak verilmiş; bu değerin toplam arazi varlığından yüksek olması değişken tanımı açısından açıklanamadığından ileri analizlerde kullanılmamıştır.

Tablo 2. Katılımcıların temel tanımlayıcı özellikleri

Değişken	Üretici (n=274)	Hane halkı (n=665)	Uzman (n=108)
Yaş (yıl), Ort. ± SS	52,39 ± 13,52	43,71 ± 13,13	-
Eğitim süresi (yıl), Ort. ± SS	8,95 ± 4,50	11,50 ± 4,73	-
Erkek katılımcı oranı (%)	89,05	77,14	-
Toplam arazi varlığı (da), Ort. ± SS	136,55 ± 338,82	-	32,41 ± 93,85

Arazi türleri ve karşılaştırma dönemleri

Tarım arazileri sulu tarla, kuru tarla ve bahçe olarak üç kategoride incelenmiştir. Sulu tarla sulama imkânına sahip; kuru tarla sulama imkânı bulunmayan tarla arazisini ifade etmektedir. Bahçe, araştırma verilerinde ayrı bir tarımsal arazi kategorisidir. Tarımsal üretim dışındaki kullanım beklentilerini yansıtan arsa değişkeni, tarım arazilerinden ayrıştırılarak tamamlayıcı analizde ele alınmıştır. Deprem öncesi dönem Aralık 2022, deprem sonrası dönem Haziran 2024'tür ve fiyatlar TL/dekar cinsindendir.

Analiz yöntemi

Aynı katılımcılara ilişkin deprem öncesi ve sonrası fiyatların karşılaştırılmasında dağılım varsayımına bağlı olmayan Wilcoxon İşaretli Sıralar Testi kullanılmıştır (Wilcoxon, 1945). Raporlanan etki büyüklüğü $r=|Z|/\sqrt{N}$ biçimindedir. Kaynak veride her karşılaştırma için geçerli eşleştirilmiş gözlem sayıları ayrı verilmediğinden etki büyüklükleri ham veriden yeniden hesaplanmamış, kaynak sonuçları korunmuştur.

İller arasındaki farklılıklar, bağımsız üç veya daha fazla grubun karşılaştırılmasına uygun Kruskal-Wallis testiyle değerlendirilmiştir (Kruskal ve Wallis, 1952).

İl bazında gerekli ham veriler yalnızca üretici-sulu tarla, üretici-kuru tarla, hane halkı-sulu tarla ve hane halkı-arsa değişkenlerinde bulunduğundan test bu dört karşılaştırmayla sınırlandırılmıştır. Bireysel ham gözlemler bulunmadığı için anlamlı sonuçlara yönelik post-hoc il çiftleri karşılaştırması yapılamamıştır. TÜFE arındırmasında TÜİK'in Aralık 2022 için 1.128,45 ve Haziran 2024 için 2.319,29 endeks değerleri kullanılmıştır (TÜİK, 2023; TÜİK, 2024). Kümülatif TÜFE artışı %105,53, dönem katsayısı 2,0553'tür. İstatistiksel anlamlılık düzeyi $p<0,05$ olarak alınmıştır.

$$\text{Nominal değişim (\%)} = [(\text{Sonraki fiyat} - \text{Önceki fiyat}) / \text{Önceki fiyat}] \times 100$$

$$\text{Reel değişim (\%)} = \{[(1 + \text{nominal değişim} / 100) / 2,0553] - 1\} \times 100$$

Değişkenlerin işlevsel tanımları

Sulu tarla, tarımsal üretimde sulama olanağı bulunan tarla arazisini; kuru tarla, üretimin doğal yağış koşullarına daha yüksek ölçüde bağlı olduğu tarla arazisini; bahçe ise kaynak veri setinde tarla kategorilerinden ayrı izlenen çok yıllık veya bahçe niteliğindeki tarımsal alanı ifade etmektedir. Arsa değişkeni, tarımsal üretim niteliğinden farklı olarak imar, yerleşim ve yatırım beklentilerinden etkilenebilecek bir kategori kabul edilmiş ve temel tarım arazisi analizine dâhil edilmemiştir.

Fiyat değişkeni TL/dekar cinsinden ifade edilmiştir. Başlangıç dönemi Aralık 2022, son dönem Haziran 2024'tür. Nominal değişim, iki dönem arasındaki parasal farkın başlangıç değerine oranıdır. Reel değişim ise nominal oranın aynı dönemdeki genel tüketici fiyat düzeyi artışına göre düzeltilmiş biçimidir. Bu tanım, arazinin tarımsal girdi maliyetlerine veya alternatif yatırım araçlarına göre reel getirisini değil, TÜFE karşısındaki satın alma gücü değişimini göstermektedir.

Veri ve yöntem sınırlılıkları

Kaynak dokümanda deprem öncesi fiyatların geriye dönük katılımcı beyanına mı yoksa ayrı bir kayıt sistemine mi dayandığı ve fiyatların aritmetik ortalama mı medyan mı olduğu açıkça belirtilmemiştir. Bu nedenle sunulan değerler kaynak verideki biçimiyle kullanılmış; sonuçlar işlem bazlı piyasa zaman serisi olarak değil, saha araştırmasına dayalı dönem karşılaştırması olarak yorumlanmıştır. Araştırma gözlemsel ve geriye dönük karşılaştırmalı olduğundan kontrol grubu içermemekte ve nedensel deprem etkisi tahmin etmemektedir.

Deprem öncesi ve sonrası tarım arazisi fiyatları

Tablo 3. Deprem öncesi ve sonrası tarım arazisi fiyatları ve Wilcoxon testi

Veri kaynağı	Arazi türü	Öncesi (TL/da)	Sonrası (TL/da)	z	p	r
Üretici	Sulu tarla	412.650	1.086.430	−11,284	<0,0001	0,681
	Kuru tarla	338.240	756.910	−10,118	<0,0001	0,611
	Bahçe	495.820	1.358.640	−11,762	<0,0001	0,710
Hane halkı	Sulu tarla	362.480	1.152.930	−17,946	<0,0001	0,696
	Kuru tarla	311.870	751.460	−16,337	<0,0001	0,633
	Bahçe	538.650	1.587.420	−18,624	<0,0001	0,722
Uzman	Sulu tarla	466.780	1.164.320	−8,121	<0,0001	0,781
	Kuru tarla	452.930	884.150	−7,586	<0,0001	0,729
	Bahçe	571.440	1.369.820	−8,348	<0,0001	0,803

Üç veri kaynağında da sulu tarla, kuru tarla ve bahçe fiyatları deprem sonrası dönemde yükselmiştir. Dokuz karşılaştırmanın tamamı istatistiksel olarak anlamlıdır ($p<0,0001$). Raporlanan etki büyüklükleri 0,611-0,803 aralığındadır. En yüksek r değeri uzmanların bahçe değerlendirmesinde, en düşük r değeri üreticilerin kuru tarla değerlendirmesinde görülmüştür.

Üretici değerlendirmeleri

Üreticilerin bildirdiği dönem fiyatlarında sulu tarla 412.650 TL/dekardan 1.086.430 TL/dekara, kuru tarla 338.240 TL/dekardan 756.910 TL/dekara ve bahçe 495.820 TL/dekardan 1.358.640 TL/dekara yükselmiştir. Her üç değişken için $p<0,0001$ olması, eşleştirilmiş fiyat sıralarındaki artışın istatistiksel olarak anlamlı olduğunu göstermektedir.

Etki büyüklüğü sulu tarlada r=0,681, kuru tarlada r=0,611 ve bahçede r=0,710'dur. Üretici grubunda en yüksek dönemsel ayrışma bahçede, görece en düşük ayrışma kuru tarlada ortaya çıkmıştır.

Hane halkı değerlendirmeleri

Hane halkı verilerinde sulu tarla fiyatı 362.480 TL/dekardan 1.152.930 TL/dekara, kuru tarla fiyatı 311.870 TL/dekardan 751.460 TL/dekara ve bahçe fiyatı 538.650 TL/dekardan 1.587.420 TL/dekara yükselmiştir. Wilcoxon testleri bütün arazi türlerinde anlamlıdır ($p<0,0001$). Etki büyüklükleri sulu tarla için r=0,696, kuru tarla için r=0,633 ve bahçe için r=0,722 olarak raporlanmıştır. Hane halkı örnekleminde de kuru tarla en düşük, bahçe en yüksek r değerine sahiptir; ancak bu sıralama fiyat artışının ekonomik nedenini tek başına açıklamamaktadır.

Uzman değerlendirmeleri

Uzman değerlendirmelerinde sulu tarla 466.780 TL/dekardan 1.164.320 TL/dekara, kuru tarla 452.930 TL/dekardan 884.150 TL/dekara ve bahçe 571.440 TL/dekardan 1.369.820 TL/dekara yükselmiştir. Üç test de $p<0,0001$ düzeyinde anlamlıdır. Sırasıyla 0,781, 0,729 ve 0,803 olan r değerleri, uzman değerlendirmelerinde dönemler arasındaki sıralı farkın güçlü olduğunu göstermektedir. En yüksek etki büyüklüğü bütün karşılaştırmalar içinde uzman-bahçe birleşiminde görülmüştür.

Nominal ve reel tarım arazisi fiyat değişimleri

Tablo 4. Tarım arazisi fiyatlarındaki nominal ve reel değişimler

Veri kaynağı	Arazi türü	Öncesi (TL/da)	Sonrası (TL/da)	Nominal (%)	Reel (%)
Üretici	Sulu tarla	412.650	1.086.430	163,28	28,10
	Kuru tarla	338.240	756.910	123,78	8,88
	Bahçe	495.820	1.358.640	174,02	33,32
Hane halkı	Sulu tarla	362.480	1.152.930	218,07	54,75
	Kuru tarla	311.870	751.460	140,95	17,23
	Bahçe	538.650	1.587.420	194,70	43,39
Uzman	Sulu tarla	466.780	1.164.320	149,44	21,36
	Kuru tarla	452.930	884.150	95,21	−5,02
	Bahçe	571.440	1.369.820	139,71	16,63

Not: Nominal oranlar tabloda gösterilen fiyatlardan; reel oranlar TÜFE dönem katsayısı 2,0553 kullanılarak yeniden hesaplanmış ve iki ondalık basamağa yuvarlanmıştır.

Dokuz arazi türü-veri kaynağı birleşiminin sekizinde reel değişim pozitiftir. En yüksek reel artış hane halkının sulu tarla değerlendirmesinde %54,76, en düşük pozitif artış üreticinin kuru tarla değerlendirmesinde %8,88'dir. Uzmanların kuru tarla değerlendirmesinde nominal artış TÜFE artışının altında kaldığından %5,02 reel kayıp ortaya çıkmıştır. Sonuçlar, yüksek enflasyon dönemlerinde nominal artışın tek başına değer kazanımı olarak yorumlanamayacağını göstermektedir.

Nominal değişimlerin grup ve arazi türüne göre değerlendirilmesi

Üretici verilerinde nominal artış bahçede %174,02, sulu tarlada %163,28 ve kuru tarlada %123,78'dir. Buna göre üç arazi türünde de fiyatlar başlangıç düzeyinin iki katını aşmış, en güçlü oransal hareket bahçede görülmüştür. Hane halkı verilerinde sulu tarla %218,07 ile en yüksek nominal artışa sahipken bahçe %194,70, kuru tarla %140,95 artmıştır. Hane halkının sulu tarla değerlendirmesi, dokuz tarım arazisi karşılaştırması içindeki en yüksek nominal değişimdir.

Uzman verilerinde sulu tarla %149,44, bahçe %139,71 ve kuru tarla %95,21 nominal artış göstermiştir. Uzmanların bildirdiği kuru tarla artışı diğer tüm tarım arazisi karşılaştırmalarından düşüktür. Gruplar arasındaki bu farklılıklar örneklem yapısı, bilgi kaynağı ve piyasa değerlendirme biçimleriyle ilişkili olabilir; ancak gruplar aynı örneklem çerçevesini paylaşmadığından oranlar arasında istatistiksel bir üstünlük sıralaması kurulmamıştır.

Reel değişimlerin değerlendirilmesi

TÜFE düzeltmesi üretici grubundaki nominal artışları sulu tarlada %28,10, kuru tarlada %8,88 ve bahçede %33,32 reel artışa indirmiştir. Böylece üretici değerlendirmelerinde bütün arazi türleri genel

tüketici fiyat düzeyinin üzerinde kalmakla birlikte kuru tarladaki reel marj sınırlı olmuştur. Hane halkı grubunda sulu tarla %54,76, kuru tarla %17,24 ve bahçe %43,39 reel artış göstermiştir. Hane halkı sonuçları, üç arazi türünün de TÜFE'nin üzerinde değer kazandığına işaret etmektedir.
Uzman grubunda sulu tarla %21,36 ve bahçe %16,63 reel artarken kuru tarla %5,02 reel azalmıştır. Buradaki reel azalış, kuru tarla fiyatının parasal olarak düşmesi değil, %95,21'lik nominal artışın aynı dönemdeki %105,53'lük TÜFE artışının altında kalması anlamına gelmektedir. Nominal ve reel yönün ayrışması, özellikle yüksek enflasyonlu dönemlerde yalnızca cari fiyatlara dayalı yorumların neden yanıltıcı olabileceğini somutlaştırmaktadır.

İller arasındaki farklılıklar
Üreticilerin sulu tarla fiyat değişimleri ile hane halkının sulu tarla ve arsa fiyat değişimleri illere göre anlamlı biçimde farklılaşmaktadır. Üreticilerin kuru tarla değerlendirmelerinde anlamlı il farkı yoktur. Anlamlı sonuçların hangi il çiftlerinden kaynaklandığı, bireysel ham gözlemler bulunmadığı için belirlenememiştir; dolayısıyla belirli bir ilin diğerlerinden daha yüksek veya düşük artış gösterdiği ileri sürülmemektedir.

Tablo 5. İller arasındaki fiyat değişimlerinin Kruskal-Wallis testi

Veri kaynağı	Arazi türü	χ^2	sd	p	η^2
Üretici	Sulu tarla	13,42	3	0,0038	0,049
	Kuru tarla	2,88	3	0,410	0,011
Hane halkı	Sulu tarla	34,18	3	<0,0001	0,102
	Arsa	42,06	3	<0,0001	0,126

İl karşılaştırmalarının ayrıntılı yorumu
Üreticilerin sulu tarla fiyat değişiminde Kruskal-Wallis istatistiği χ^2=13,42 ve p=0,0038'dir. Sonuç, dört ilin sıralı fiyat değişimlerinin aynı dağılımdan geldiği varsayımına karşı kanıt sunmaktadır; tamamlayıcı η^2 değeri 0,049'dur. Üreticilerin kuru tarla fiyat değişiminde ise χ^2=2,88 ve p=0,410 olduğundan iller arası fark istatistiksel olarak desteklenmemiştir; bu karşılaştırmada η^2=0,011'dir.
Hane halkının sulu tarla değerlendirmesinde χ^2=34,18, p<0,0001 ve η^2=0,102; arsa değerlendirmesinde χ^2=42,06, p<0,0001 ve η^2=0,126'dır. Bu iki bulgu, özellikle hane halkının değerlendirdiği sulu tarla ve arsa değişimlerinin mekânsal olarak homojen olmadığını göstermektedir. Ancak Kruskal-Wallis testi yalnızca en az bir il dağılımının farklı olduğunu bildirir. Ham gözlemler ve çoklu karşılaştırma sonuçları bulunmadığından farklılığın hangi il veya il çiftlerinden kaynaklandığı, yönü ve büyüklüğü belirlenememektedir.

Arsa fiyatlarına ilişkin tamamlayıcı bulgular
Arsa fiyatları her iki veri kaynağında nominal olarak artmış ve Wilcoxon sonuçları anlamlı bulunmuştur. Ancak hane halkı değerlendirmesi %64,39 reel artışa, uzman değerlendirmesi %6,99 reel azalışa işaret etmektedir. Bu ayrışma, farklı piyasa aktörlerinin aynı döneme ilişkin değerlendirmelerinin farklılaşabileceğini göstermektedir. Arsa; imar, konutlaşma ve kentsel gelişme beklentilerinden etkilenebildiği için tarım arazileriyle aynı piyasa kategorisinde yorumlanmamıştır.

Tablo 6. Arsa fiyat değişimine ilişkin sonuçlar

Veri kaynağı	Öncesi (TL/da)	Sonrası (TL/da)	Nominal (%)	Reel (%)	Z	p
Hane halkı	735.920	2.486.510	237,88	64,39	−19,442	<0,0001
Uzman	806.530	1.541.780	91,16	−6,99	−7,442	<0,0001

Bulguların araştırma soruları çerçevesinde özeti
Birinci araştırma sorusu bakımından, dokuz tarım arazisi ve iki arsa karşılaştırmasının tamamında deprem sonrası nominal fiyatların anlamlı biçimde yükseldiği görülmüştür. İkinci araştırma sorusunda nominal artışların reel dönüşüm sonrasında aynı büyüklükte korunmadığı; dokuz tarım arazisi sonucundan sekizinin pozitif, uzman-kuru tarla sonucunun negatif olduğu belirlenmiştir.
Üçüncü araştırma sorusu açısından değişimin arazi türüne ve veri kaynağına göre farklılaştığı görülmekle birlikte bu gruplar arasındaki farklar doğrudan istatistiksel olarak sınanmamıştır.

Dördüncü araştırma sorusunda ise mevcut dört karşılaştırmanın üçünde anlamlı il farklılığı bulunmuş, üretici-kuru tarla değişiminde farklılık saptanmamıştır. Böylece bulgular hem zaman boyutunda ortak bir nominal artışa hem de reel, aktör ve mekân boyutlarında heterojen bir görünüme işaret etmektedir.

TARTIŞMA

Nominal artışın reel karşılığı

Bulgular, üç farklı veri kaynağında da tarım arazisi fiyatlarının deprem sonrası dönemde güçlü bir nominal hareket yaşadığını göstermektedir. Ancak Aralık 2022-Haziran 2024 döneminde TÜFE'nin %105,53 artmış olması, cari fiyat hareketinin önemli bir bölümünün genel fiyat düzeyiyle birlikte değerlendirilmesini zorunlu kılmaktadır. TÜFE ile arındırma sonrasında oranların belirgin biçimde gerilemesi, nominal fiyat değişiminin ekonomik değer değişimiyle özdeş olmadığını göstermiştir. Bu yaklaşım, farklı dönemlerdeki parasal değerlerin ortak bir fiyat düzeyine taşınması gerektiğini vurgulayan endeks metodolojisiyle uyumludur (ILO vd., 2020).

Bununla birlikte dokuz tarım arazisi karşılaştırmasının sekizinde reel değişimin pozitif kalması, gözlenen hareketin yalnızca genel tüketici enflasyonu görünümünden ibaret olmadığını göstermektedir. Bu sonuç, araziye özgü bir fiyat bileşeninin varlığıyla uyumludur; ancak bileşenin kaynağı mevcut tasarımla ayrıştırılamaz. Faiz, tarımsal gelir beklentileri, alternatif yatırım talebi ve makroekonomik koşullar arazi fiyatını eş zamanlı etkileyebildiğinden (Just ve Miranowski, 1993; Goodwin vd., 2003), pozitif reel değişimin tamamını depremle ilişkilendirmek metodolojik olarak doğru değildir.

Arazi türlerine göre farklılaşma

Arazi türleri arasındaki farklılaşma, tarım arazisinin homojen bir varlık olmadığını göstermektedir. Sulama kapasitesi, toprak özellikleri, üretim deseni, parsel büyüklüğü, konum ve ulaşılabilirlik hem üretim gelirini hem de alıcıların geleceğe ilişkin beklentilerini etkileyebilir (Maddison, 2000; Bastian vd., 2002; Huang vd., 2006; Tsoodle vd., 2006). Tarım dışı kullanım potansiyeli ve kentsel baskı da tarımsal getiriden bağımsız bir değer bileşeni yaratabilmektedir (Plantinga vd., 2002; Borchers vd., 2014).

Üretici grubunda bahçenin, hane halkında sulu tarlanın en yüksek reel artışı göstermesi; uzman-kuru tarla değerlendirmesinin ise negatif reel sonuca dönüşmesi bu heterojenlikle uyumludur. Bununla birlikte arazi nitelikleri parsel düzeyinde ölçülmediği ve çok değişkenli bir fiyat modeli kurulmadığı için, farklılıkların sulamadan, ürün deseninden, konumdan veya başka bir özellikten kaynaklandığı ileri sürülemez. Bulgular, belirli bir açıklamayı doğrulamak yerine sonraki araştırmalarda hangi değişkenlerin birlikte ele alınması gerektiğini göstermektedir (Kostov, 2009; Tavares vd., 2022).

Afet ve gayrimenkul literatürüyle karşılaştırma

Deprem riskini inceleyen uluslararası çalışmalar çoğunlukla konut ve kentsel arazi piyasalarında risk iskontosu bildirmiştir. Brookshire vd. (1985) ve Beron vd. (1997), tehlike bilgisinin ve deprem deneyiminin mülk değerlerine yansıyabildiğini göstermiştir. Japonya örneklerinde de yüksek risk, arazi ve konut fiyatlarında iskonto ile ilişkilendirilmiştir (Nakagawa vd., 2009; Naoi vd., 2009; Gu vd., 2018). Bu araştırmadaki yaygın reel artış görünümü, söz konusu çalışmalarla yüzeysel olarak farklı bir yön göstermektedir.

Bu farklılık bir çelişki olarak okunmamalıdır. Önceki çalışmaların önemli bölümü kentsel konut veya yapılaşmış araziyi incelerken burada üretim faktörü ve servet unsuru niteliğindeki tarım arazisi ele alınmaktadır. Ayrıca fiyatların ölçülme biçimi, incelenen zaman aralığı, yerel arz-talep koşulları ve afet sonrası kamu müdahaleleri farklıdır. Afet kaynaklı damgalanma ile desteklerin veya yeniden yapılanma talebinin karşıt yönlü etkiler oluşturabileceği de literatürde tartışılmaktadır (Messer vd., 2006; Lee vd., 2021). Dolayısıyla afet sonrası fiyatın yönü, risk algısının tek başına belirlediği sabit bir sonuç değildir.

Veri kaynakları arası yakınsama ve ayrışma

Üretici, hane halkı ve uzman örneklemleri istatistiksel olarak birleştirilemez. Bununla birlikte üç bağımsız kaynağın bütün tarım arazisi türlerinde nominal artış yönünde sonuç vermesi, fiyat hareketinin tek bir katılımcı grubunun değerlendirmesine özgü olmadığını destekleyen bir veri çeşitliliği sağlamaktadır. Bu yakınsama, farklı aktörlerin aynı döneme ilişkin ortak yönlü gözlemine işaret eder; nedensel doğrulama, ölçüm eşdeğerliği veya sonuçların bütün nüfusa genellenebilirliği anlamına gelmez.

Gruplar reel artışların büyüklüğü bakımından ise ayrışmaktadır. Hane halkı değerlendirmeleri sulu tarla ve bahçede daha yüksek oranlara, uzman değerlendirmeleri özellikle kuru tarlada daha düşük bir sonuca işaret etmektedir. Arsa değişkeninde yönün dahi farklılaşması, aktörlerin eriştiği işlem bilgisi, referans aldığı yerleşim alanı veya beklenti ufku bakımından farklılaşabileceğini düşündürür. Bu olası açıklamalar anket formunda doğrudan ölçülmediği için bulgu, veri kaynağına göre heterojenlik olarak sınırlandırılmıştır.

Mekânsal heterojenlik ve arsa-tarım arazisi ayrımı

İller arasındaki anlamlı farklılıklar; hasar düzeyi, yeniden yapılanma, göç, altyapı, yerel talep ve arazi kullanım beklentilerinin bölgeler arasında aynı olmayabileceğini düşündürmektedir. SBB (2023) ve FAO (2023) değerlendirmeleri de tarımsal hasar ile iyileşme gereksinimlerinin sektör ve yer bakımından farklılaştığını göstermektedir. Bununla birlikte bu değişkenler veri setinde doğrudan ölçülmediğinden, elde edilen istatistikler yalnızca mekânsal heterojenliğin varlığını ortaya koymaktadır; hangi ilin hangi mekanizma nedeniyle ayrıştığını göstermemektedir.

Hane halkı ve uzmanların arsa sonuçlarındaki belirgin ayrışma, tarım arazisi ile arsanın aynı ekonomik kategori altında değerlendirilmemesi gerektiğini güçlendirmektedir. Tarım arazisinin değeri üretim kapasitesi ve tarımsal gelirle bağlantılıyken arsa; imar hakkı, konut talebi, yeniden yerleşim ve kentsel gelişme beklentilerine daha duyarlı olabilir. Bu nedenle arsa bulgusu tarım arazisi sonuçlarını doğrulayan bir tekrar değil, afet sonrası arazi piyasasının farklı bir kesitini gösteren tamamlayıcı bir göstergedir.

Araştırmanın sınırlılıkları

Araştırmanın temel sınırlılığı gözlemsel ve geriye dönük karşılaştırmalı tasarımdır. Kontrol grubu, deprem öncesini ve sonrasını kapsayan uzun dönemli işlem serisi ve parsel düzeyinde hasar göstergeleri bulunmadığı için fiyat değişimleri doğrudan depremin etkisi olarak tanımlanamaz.

Deprem öncesi fiyatların elde edilme yöntemi açık değildir. Değerler geriye dönük beyana dayanıyorsa hatırlama yanlılığı sonuçların büyüklüğünü etkileyebilir. Ayrıca tabloda sunulan fiyatların ortalama mı medyan mı olduğu ve her eşleştirilmiş testte kullanılan geçerli gözlem sayısı belirtilmemiştir.

TÜFE genel tüketici fiyat düzeyini temsil etmektedir; tarımsal üretim maliyetlerini, araziye özgü alternatif yatırım getirisini veya yerel gayrimenkul endeksini doğrudan ölçmez. Bu nedenle reel sonuçlar, tarım arazisinin bütün ekonomik değer boyutlarını değil, genel tüketici fiyat düzeyine göre değer değişimini göstermektedir.

Uzman örnekleminin illere göre dengesiz dağılması ve il bazında ham verilerin yalnızca dört karşılaştırma için bulunması, mekânsal sonuçların kapsamını sınırlandırmaktadır. Post-hoc analiz yapılamadığı için anlamlı farklılığın hangi il çiftlerinden kaynaklandığı belirlenememiştir.

SONUÇ

Temel sonuçlar

Adıyaman, Hatay, Kahramanmaraş ve Malatya'da deprem sonrası tarım arazisi fiyatları üretici, hane halkı ve uzman verilerinde nominal olarak artmıştır. Enflasyondan arındırıldığında artışların büyüklüğü azalmış; buna rağmen dokuz karşılaştırmanın sekizinde reel artış devam etmiştir. Uzmanların kuru tarla değerlendirmesi %5,02 reel kayba işaret etmektedir.

Reel değişim arazi türüne ve veri kaynağına göre farklılaşmıştır. En yüksek tarım arazisi reel artışı hane halkının sulu tarla değerlendirmesinde %54,75'dir. Arsa değerlendirmelerinde ise hane halkı ve uzman sonuçları farklı yönlere ayrılmıştır. Bazı göstergelerde iller arasında anlamlı farklılık bulunması, fiyat hareketlerinin mekânsal olarak homojen olmadığını göstermektedir.

Bu sonuçların doğru ifadesi, 'depremin arazi fiyatlarını artırdığı' değil, 'deprem sonrası dönemde arazi fiyatlarında nominal ve çoğu karşılaştırmada reel artış gözlendiği' biçimindedir. Araştırmanın veri yapısı, gözlenen değişimi depremden veya aynı dönemde gerçekleşen diğer ekonomik gelişmelerden nedensel olarak ayırmaya yeterli değildir.

Politika önerileri

Afet bölgelerinde arazi fiyatları yalnızca nominal tutarlarla değil, düzenli olarak enflasyondan arındırılmış reel göstergelerle birlikte izlenmelidir. Böylece genel fiyat düzeyindeki değişim ile arazi piyasasına özgü hareketler ayrıştırılabilir.

Kamulaştırma, yeniden yerleşim, arazi edinimi ve tarımsal destek uygulamalarında güncel bölgesel değerler ile arazi türleri birlikte dikkate alınmalıdır. İller ve arazi türleri arasındaki farklılıklar, tek bir standart değerin her koşulda yeterli olmayabileceğini göstermektedir.
Tarım arazisinin üretim niteliği ile konutlaşma veya yatırım amaçlı arsa talebi ayrıştırılmalıdır. Afet sonrası değerleme sistemlerinde sulama durumu, parsel büyüklüğü, toprak özellikleri, konum, kullanım biçimi ve imar beklentileri standart değişkenler olarak kaydedilmelidir.
Gelecek araştırmalarda işlem bazlı fiyatların daha uzun zaman serileriyle izlenmesi, hasar ve mekânsal değişkenlerin modellere eklenmesi ve depremden etkilenmeyen uygun karşılaştırma bölgelerinin kullanılması önerilmektedir. Bu veri yapısı, deprem ile arazi fiyatları arasındaki ilişkinin daha güçlü nedensel yöntemlerle incelenmesini sağlayacaktır.

Gelecek araştırmalar için öneriler

İlk olarak, tapu işlemleri veya doğrulanabilir piyasa kayıtlarından üretilecek parsel düzeyinde bir fiyat paneli kurulmalıdır. Aynı parselin veya karşılaştırılabilir parsellerin deprem öncesi ve sonrası işlemlerini izleyen daha uzun bir zaman serisi; geçici şoklar ile kalıcı değer değişimlerini ayırmayı kolaylaştıracaktır. İşlem fiyatına sulama durumu, parsel büyüklüğü, toprak niteliği, eğim, yola ve yerleşime uzaklık, ürün deseni, imar beklentisi ve doğrudan hasar göstergelerinin eşlenmesi, hedonik ve mekânsal modellerin kurulmasına olanak sağlayacaktır (Rosen, 1974; Kostov, 2009).
İkinci olarak, depremden etkilenmeyen fakat deprem öncesinde benzer tarımsal ve ekonomik özelliklere sahip karşılaştırma bölgeleri belirlenmelidir. Çok dönemli gözlemlerle farkların farkı, olay çalışması veya uygun eşleştirme yöntemlerinin kullanılması, eş zamanlı enflasyon ve makroekonomik gelişmelerin etkisini depremle ilişkili değişimden daha güçlü biçimde ayırabilir. Risk algısı, göç, yeniden yapılanma talebi ve kamu destekleri ayrıca ölçülerek kuramsal mekanizmalar doğrudan sınanmalıdır.
Üçüncü olarak, üretici, hane halkı ve uzman değerlendirmelerinin neden farklılaştığı nitel ve nicel yöntemlerin birlikte kullanıldığı tasarımlarla araştırılmalıdır. Katılımcıların referans aldığı coğrafi alan, bilgi kaynağı, yakın dönem işlem deneyimi ve fiyat beklentisi ölçülürse veri kaynakları arasındaki ayrışmanın ölçüm farkından mı yoksa gerçek piyasa segmentasyonundan mı kaynaklandığı daha açık biçimde değerlendirilebilir. Böyle bir yaklaşım, afet sonrası arazi değerlemesinde kullanılacak veri kaynağının geçerliliğini de güçlendirecektir.

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EARTHQUAKE-INDUCED DISRUPTIONS AND THE RECONFIGURATION OF AGRICULTURAL LAND MARKETS: EVIDENCE FROM PRODUCER BEHAVIOR IN TÜRKİYE[41]

DEPREM KAYNAKLI BOZULMALAR VE TARIM ARAZİSİ PİYASALARININ YENİDEN YAPILANMASI: TÜRKİYE'DE ÜRETİCİ DAVRANIŞLARINDAN BULGULAR[1]

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ABSTRACT

The February 2023 earthquakes in Türkiye caused profound disruptions in rural livelihoods and agricultural production systems. Beyond their immediate physical and economic impacts, these shocks have significantly altered the functioning of agricultural land markets in the affected regions.

This study investigates changes in agricultural land prices and producers' land market behavior in four heavily affected provinces-Adıyaman, Hatay, Kahramanmaraş, and Malatya. The analysis is based on a structured survey conducted with 271 agricultural enterprises in the earthquake-affected region. To better capture producers' responses, a binary logit model was employed to identify the factors influencing producers' land sale decisions.

The findings reveal a substantial increase in agricultural land prices following the earthquake across all land types. This rise is particularly pronounced for irrigated and orchard lands, suggesting a shift toward location- and risk-related considerations rather than traditional productivity-based factors. In parallel, the results indicate a notable transformation in producers' land market behavior.

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The econometric analysis shows that the tendency to sell land is primarily driven by earthquake-related effects, while conventional socio-economic characteristics do not exhibit a statistically significant influence.
Overall, the findings suggest that the earthquake has not only disrupted production conditions but also triggered a structural reconfiguration of agricultural land markets. These emerging dynamics are likely to increase production costs, alter land allocation patterns, and pose serious challenges for the long-term sustainability of agricultural activities in the region.
Keywords: Earthquake, Türkiye, agricultural land, land prices, farmer behavior, logit model.

ÖZET

Türkiye'de Şubat 2023'te meydana gelen depremler, kırsal geçim kaynakları ve tarımsal üretim sistemlerinde önemli bozulmalara neden olmuştur. Bu şoklar, doğrudan fiziksel ve ekonomik etkilerinin ötesinde, depremden etkilenen bölgelerde tarım arazisi piyasalarının işleyişini de önemli ölçüde değiştirmiştir.
Bu çalışmada, depremden ağır şekilde etkilenen dört ilde—Adıyaman, Hatay, Kahramanmaraş ve Malatya—tarım arazisi fiyatlarındaki değişimler ile üreticilerin arazi piyasasındaki davranışları incelenmiştir. Analiz, depremden etkilenen bölgede 271 tarım işletmesi ile gerçekleştirilen yapılandırılmış anket çalışmasına dayanmaktadır. Üreticilerin tepkilerini daha iyi ortaya koymak amacıyla, üreticilerin arazi satma kararlarını etkileyen faktörleri belirlemek üzere ikili lojit (binary logit) modeli kullanılmıştır.
Bulgular, deprem sonrasında tüm arazi türlerinde tarım arazisi fiyatlarında önemli bir artış meydana geldiğini göstermektedir. Bu artış özellikle sulu tarım arazileri ve meyve bahçelerinde daha belirgin olup, arazi piyasasında geleneksel verimlilik temelli faktörlerden ziyade konum ve riskle ilişkili unsurlara doğru bir yönelimin olduğunu düşündürmektedir. Bununla birlikte, bulgular üreticilerin arazi piyasası davranışlarında da dikkate değer bir dönüşüm yaşandığını ortaya koymaktadır. Ekonometrik analiz sonuçları, arazi satma eğiliminin esas olarak deprem kaynaklı etkiler tarafından belirlendiğini, buna karşılık geleneksel sosyo-ekonomik özelliklerin istatistiksel olarak anlamlı bir etkiye sahip olmadığını göstermektedir.
Genel olarak bulgular, depremin yalnızca üretim koşullarını bozmakla kalmadığını, aynı zamanda tarım arazisi piyasalarında yapısal bir yeniden yapılanmayı da tetiklediğini ortaya koymaktadır. Ortaya çıkan bu dinamiklerin üretim maliyetlerini artırması, arazi kullanım ve tahsis modellerini değiştirmesi ve bölgedeki tarımsal faaliyetlerin uzun vadeli sürdürülebilirliği açısından ciddi sorunlar oluşturması beklenmektedir.
Anahtar Kelimeler: Deprem, Türkiye, tarım arazisi, arazi fiyatları, çiftçi davranışı, lojit modeli.

INTRODUCTION

Agricultural land occupies an unusual place in rural economies. It is a productive input, but it is also a household's principal store of wealth, a source of collateral and an asset passed between generations. A change in its price therefore affects far more than the cost of farming. It alters entry and expansion opportunities, the borrowing capacity of landowners and, in difficult periods, the resources available to households trying to remain in agriculture. The standard capitalization approach treats farmland value as the discounted stream of expected future returns. In practice, those expectations are formed from a wider set of influences: farm income, inflation and interest rates, credit conditions, public support, local accessibility and the prospect of future development all enter the price of land (Just & Miranowski, 1993; Plantinga et al., 2002; Deaton & Lawley, 2022). Productive attributes such as soil quality and irrigation consequently interact with proximity to markets, infrastructure and competing non-agricultural uses (Nilsson & Johansson, 2013). A recent systematic review of the farmland-pricing literature confirms that these two sets of influences typically interact rather than operate separately, and that environmental hazard exposure itself behaves as a nonlinear price determinant: moderate flood risk has been found to be capitalized as a modest positive amenity in some markets, while severe or recurrent risk depresses value, so hazard exposure does not translate into a single, predictable price effect (Agosta et al., 2025). This mixed character of farmland—as both a working asset and a claim on future land use—becomes particularly important after a large disaster.

An earthquake unsettles several components of land value at the same time. Damage to irrigation systems, farm buildings, machinery, storage, roads and processing facilities can lower expected agricultural returns. Mortality, injury, displacement and labour shortages can interrupt production even where fields remain physically usable. Yet the same event may generate reconstruction activity, new infrastructure, temporary settlement and the relocation of households or firms. These processes can increase demand for land in some places while weakening it elsewhere. New information about seismic exposure may also change what buyers are willing to pay for particular locations. There is therefore no single, theoretically necessary direction for post-earthquake prices. The loss of productive capacity and heightened risk point towards lower values; scarcity, reconstruction demand, inflation and expectations of conversion may work in the opposite direction. The broader disaster literature makes the same distinction between direct asset destruction and the indirect adjustments that follow through production, employment and reconstruction (Botzen et al., 2019). Farmland-specific evidence sharpens this ambiguity rather than resolving it: transaction-level analysis of Taiwan's agricultural disaster-relief programme finds that relief payments were capitalized negatively into affected farmland prices, with the discount concentrated in peri-urban parcels valued for their conversion potential, suggesting that public support intended to offset damage can leave a lasting stigma on a parcel instead of restoring its value (Lee et al., 2021).

Evidence that markets capitalize newly salient hazard information comes mainly from housing. Following major earthquakes in Japan, the discount attached to locations exposed to seismic risk became larger, indicating that a realized disaster changed buyers' assessment of a previously low-probability event (Naoi et al., 2009). The 2023 Kahramanmaraş earthquake sequence appears to have produced a comparable reassessment beyond the directly damaged region. In Istanbul, post-earthquake increases in house prices and rents were more subdued in high-risk neighbourhoods than in lower-risk neighbourhoods; the discount on older buildings was also greater where seismic risk was high (Çepni et al., 2026). Such findings are useful, but they cannot simply be transferred to farmland. A dwelling is valued principally for shelter and location. Agricultural land derives value from current production, household wealth, possible development and, in many cases, an owner's ability to continue farming. A disaster may therefore affect its price and its ownership through different, sometimes opposing, channels.

The ownership response deserves separate attention. Where formal insurance and affordable credit are limited, selling land can provide urgently needed liquidity after a shock. It may settle debt or finance housing and business recovery, but it can also remove the asset on which future farm income depends. Long-run panel evidence from India shows that repeated adverse shocks increased participation in land-sale markets, although the presence of banks reduced part of this effect (Deininger et al., 2009). A study of distress sales in rural Kenya reaches a similar conclusion: larger monetary and material losses increased the likelihood of sale, while education, livestock wealth, road access, landholding and the household's social environment shaped the response (Musyoka et al., 2021). These studies caution against interpreting every transaction as an ordinary portfolio choice. After a severe shock, the same sale may express financial distress, a reassessment of farming prospects or an attempt to move capital into a less exposed activity. The same pattern is not confined to earthquakes or to South Asia's agrarian economies: panel evidence from rural Bangladesh shows that repeated flood and cyclone exposure raises the probability that affected households leave agriculture and relocate altogether, indicating that disaster-driven land and livelihood adjustment is a general feature of covariate shocks rather than a peculiarity of the present setting (Gray & Mueller, 2012).

Research conducted in Türkiye before the 2023 earthquakes provides a useful, though necessarily incomplete, benchmark. A national study of the land market following changes in land legislation found that participation as a buyer or seller was associated with farmers' direct involvement in agriculture, education and non-farm income. Farm size and productivity were important in price formation, while indebtedness was a prominent reason for sale (Özdemir et al., 2022). Work on farm exit in İzmir likewise identifies age, farm size and type, ownership, financial pressure and agricultural support as relevant to whether producers expect to remain in farming (Türkekul & Abay, 2024). These findings show that land transactions already reflected household life cycles, farm structure and financial constraints. What they cannot establish is whether those relationships persist when physical destruction, displacement and an abrupt reordering of local demand occur together.

The earthquakes of 6 February 2023 provide an exceptional setting in which to examine that question. The eleven affected provinces formed a major part of Türkiye's agrifood economy. FAO reported that they accounted for more than 20% of national food production, close to 15% of agricultural gross domestic product and almost 20% of agrifood exports. Its initial assessment placed damage to agriculture at USD 1.3 billion and associated losses at USD 5.1 billion (Food and Agriculture Organization of the United Nations [FAO], 2023a). The official recovery and reconstruction assessment recorded 307,355 registered farmers in the region—14% of the national total—and estimated that about 450,000 hectares of planted land had been adversely affected (Presidency of the Republic of Türkiye, Presidency of Strategy and Budget, 2023). The scale of exposure meant that disruption to rural production was not a secondary consequence of the disaster; it was central to the region's economic and social recovery.

The agricultural shock extended beyond damaged fields. FAO's recovery plan documents losses to livestock shelters, irrigation, storage, fisheries, processing capacity and rural infrastructure, together with restricted access to inputs and markets. Displacement and migration also reduced labour availability and placed the continuity of many enterprises at risk (FAO, 2023b). Subsequent field evidence confirms both the severity and the unevenness of these effects. Firms in Malatya reported difficulties in production, procurement, logistics and marketing (Aydın Can et al., 2024), while a comparative study of Adıyaman and Malatya found that labour and recovery constraints differed materially between provinces (Dinçer et al., 2024). Evidence from Adıyaman, Hatay, Kahramanmaraş and Malatya further shows that changes in living and working conditions continued well beyond the emergency phase (International Labour Organization & International Organization for Migration, 2024). Taken together, this literature describes a rural economy in which productive capacity, labour supply, market access and household location were all being renegotiated. It says much less about the land market through which part of that adjustment may occur.

That omission is consequential. If land prices rise while agricultural earnings and farm infrastructure remain impaired, expansion becomes more difficult for producers with limited capital. If sales are prompted by urgent liquidity needs, ownership may shift away from households that would otherwise have continued farming. Reconstruction and non-farm demand may also redirect land towards uses that bear little relation to its agricultural productivity. Over time, these changes can influence farm size, land concentration, production costs and the survival of orchards or irrigated systems that require long investment horizons. Price and sale behaviour therefore need to be examined together: the first records how the market values land after the shock, while the second reveals which producers are most likely to relinquish it.

The present study examines these two dimensions in Adıyaman, Hatay, Kahramanmaraş and Malatya, four provinces that sustained extensive damage and where agriculture remains economically important. It draws on a structured survey of 271 agricultural enterprises. Producer-reported prices before and after the earthquakes are compared for irrigated land, dry land and orchards, categories with different productive capacities and investment profiles. A binary logit model then relates the tendency to sell land to age, education, farming experience, farm size, post-earthquake demand and the perceived influence of the earthquake on the decision. The price comparison is descriptive, not a claim to have isolated a causal earthquake effect: nominal values were also exposed to inflation and wider asset-price adjustment (Just & Miranowski, 1993). The two measures are therefore interpreted together.

By bringing land type, price change and producer behaviour into the same analysis, the study connects three literatures that have largely developed apart: farmland capitalization, household responses to shocks and the economic consequences of the 2023 earthquakes. Its focus on agricultural land also addresses an important gap in post-disaster property research, which has been dominated by housing. The purpose is not to attribute all observed movement to a single mechanism. It is to identify how a major disaster became entangled with productive conditions, liquidity pressure, changing demand and expectations about land use—and to show why the resulting land-market adjustment matters for the durability of agricultural recovery in southern Türkiye.

RESEARCH AND FINDINGS

Study area and research design

The study used a cross-sectional farm survey with a retrospective before-and-after component. Fieldwork covered eight districts in four provinces severely affected by the earthquakes of 6 February 2023: Dulkadiroğlu and Onikişubat in Kahramanmaraş; Yeşilyurt and Battalgazi in Malatya; Antakya and Kırıkhan in Hatay; and Central District and Gölbaşı in Adıyaman. These districts were included because they combined extensive earthquake damage with strong pressure on rural land and a pronounced interface between agricultural and urban uses. This made it possible to examine land-market adjustment in locations where disruption to farming coincided with changing residential and reconstruction demand.

The wider field programme also included institutional land records, interviews with local stakeholders and a separate household survey. The analytical dataset used in this article is restricted to the structured survey of agricultural enterprises. It therefore concerns producers' reported land values and sale behaviour; household demand, hedonic pricing and income capitalization fall outside the analysis reported here.

Sampling and data collection

The target population consisted of agricultural enterprises operating in the eight study districts. The required sample size was calculated for estimation of a population proportion under simple probability sampling (Cochran, 1977):

$$n = \frac{z^2 p(1-p)}{d^2},$$

where n is the minimum sample size, z is the critical value for the chosen confidence level, p is the expected proportion and d is the margin of error. With $z = 1.645$ for a 90% confidence level, $p = 0.50$, and $d = 0.05$, the calculation yielded 270.6 observations; this value was rounded to 271 agricultural enterprises. The use of $p = 0.50$ gives the largest variance and therefore the most conservative sample size when the population proportion is unknown. The sample was distributed among the districts in proportion to district population.

Data were obtained through a structured questionnaire administered at enterprise level. The questionnaire recorded the operator's age, education and farming experience; the total area operated; rental values for irrigated and dry land; and reported agricultural land prices before and after the earthquakes. Prices were collected separately for irrigated land, dry land and orchards because these categories differ in productive capacity, water dependence and investment horizon. The survey also recorded producers' perceptions of post-earthquake land demand, whether the earthquake had affected their land-sale decision and whether they were inclined to offer land for sale.

Farm area and land values were expressed per decare (da), where 1 da equals 1,000 m² or 0.1 ha. Monetary values are reported in Turkish lira per decare (TRY/da). The price series presented in this article are nominal. They should therefore be read as observed market movements over the study period, not as real-price changes attributable exclusively to the earthquake.

Variables

The descriptive analysis covered education and farming experience in years, farm size in decares, and irrigated- and dry-land rents in TRY/da. The price analysis used the reported value of irrigated, dry and orchard land before and after the earthquakes. For each land type, percentage change was calculated as

$$\text{Change (\%)} = 100 \times \frac{P_{\text{after}} - P_{\text{before}}}{P_{\text{before}}}.$$

The outcome in the econometric analysis was the producer's land-sale tendency. It was coded as 1 when the producer indicated a tendency to offer agricultural land for sale and 0 otherwise. Explanatory variables were age, years of education, years of farming experience, log-transformed farm size, perceived post-earthquake demand and the reported influence of the earthquake on the sale decision. The last two variables were entered as questionnaire-derived indicators. Their interpretation is therefore conditional on the response coding used in the survey instrument.

Statistical analysis

Continuous variables were summarized using the mean, standard deviation, minimum and maximum. Mean prices before and after the earthquakes were compared separately for irrigated land, dry land and orchards. Because both observations referred to the same surveyed enterprise, paired-samples t-tests were used to test whether the mean within-enterprise change differed from zero (Field, 2018). The comparison was conducted separately by land type so that differences in production systems and capital intensity were not obscured by a single pooled estimate.

A binary logit model was estimated to identify factors associated with land-sale tendency (Hosmer et al., 2013). For producer i, the model can be written as

$$\Pr(Y_i = 1 \mid \mathbf{X}_i) = \frac{\exp(\beta_0 + \mathbf{X}_i'\boldsymbol{\beta})}{1 + \exp(\beta_0 + \mathbf{X}_i'\boldsymbol{\beta})},$$

where Y_i denotes land-sale tendency, $\mathbf{X}_i$ is the vector of explanatory variables, β_0 is the intercept and $\boldsymbol{\beta}$ is the vector of estimated coefficients. Farm size was entered in logarithmic form to reduce the influence of the strongly right-skewed landholding distribution. Results are reported as coefficients, standard errors, odds ratios $[\exp(\beta_j)]$ and two-sided p-values. Statistical significance was evaluated at the 5% level; results with $0.05 \leq p < 0.10$ were treated as marginal evidence rather than conventionally significant effects.

The analysis is associational. The design contains neither a contemporaneous unaffected control group nor independently observed transaction prices for every enterprise. The t-tests establish whether surveyed producers reported systematic before-and-after differences, while the logit model identifies characteristics associated with sale tendency. Neither analysis, on its own, identifies the earthquake's isolated causal effect.

RESULTS

Characteristics of surveyed enterprises

The surveyed enterprises were managed by producers with an average of 8.95 years of schooling and nearly 28 years of farming experience (Table 1). Farm size varied substantially. Although the mean operated area was 136.55 da, the standard deviation was 338.82 da and the largest enterprise covered 3,100 da. This dispersion indicates that the sample brought together very small operations and a smaller number of much larger enterprises, supporting the use of the logarithmic transformation in the regression analysis. The heterogeneity is also relevant to interpretation because pre-earthquake evidence from Türkiye identifies farm scale and productivity as important correlates of agricultural land-market participation and price formation (Özdemir et al., 2022).

Rental values were similarly uneven, particularly for irrigated land. The mean irrigated-land rent was TRY 7,835.37/da, but its standard deviation exceeded TRY 24,500/da and the maximum reached TRY 150,000/da. Dry-land rents were lower and more tightly distributed, with a mean of TRY 941.67/da and a range of TRY 150–2,000/da. This contrast is consistent with the broader literature showing that agricultural land values capitalize productive attributes and local conditions, including irrigation, market accessibility and development pressure (Nilsson & Johansson, 2013; Deaton & Lawley, 2022). The present descriptive statistics do not contain parcel-level measures of these attributes, however, so the sources of the wide within-category dispersion cannot be separated empirically.

Table 1. Descriptive Statistics of Surveyed Agricultural Enterprises

Variable	Mean	Std. deviation	Minimum	Maximum
Education (years)	8.95	4.50	0	18
Farming experience (years)	27.97	14.43	1	60
Farm size (da)	136.55	338.82	1.5	3,100
Irrigated-land rent (TRY/da)	7,835.37	24,533.68	200	150,000
Dry-land rent (TRY/da)	941.67	624.83	150	2,000

Note: da = decare; TRY = Turkish lira.

Reported changes in agricultural land prices

Producer-reported nominal land prices rose sharply after the earthquakes in all three land categories (Table 2). Orchard land recorded the largest proportional increase, from TRY 481,470.59/da to TRY 1,323,058.82/da, an increase of 174.80%. The corresponding increase was 165.27% for irrigated land and 123.02% for dry land. Thus, even the smallest proportional change represented more than a doubling of the reported mean price. This ordering — orchards appreciating most, followed by irrigated land and then dry land — is the study's central price finding: it shows that the post-earthquake repricing was not a uniform inflationary drift but tracked the productive and investment intensity of each land category.

The paired comparisons were statistically significant for irrigated land, dry land and orchards (all $p < 0.001$). The larger proportional changes observed for orchards and irrigated land are compatible with the established finding that land markets capitalize differences in productive capacity, location and expected future use (Nilsson & Johansson, 2013; Deaton & Lawley, 2022). This interpretation remains provisional because the survey did not estimate the contribution of each mechanism separately.

The regional context nevertheless matters. Post-earthquake field research documents disruptions to production, procurement, logistics, labour availability and recovery across the study provinces (Aydın Can et al., 2024; Dinçer et al., 2024; International Labour Organization & International Organization for Migration, 2024). Such disruptions can alter both expected agricultural returns and households' demand for liquidity. A structurally similar reallocation toward higher-value production has been documented after other major earthquakes: in Nepal, the 2015 Gorkha earthquake accelerated an existing shift among smallholders from subsistence toward cash-crop farming, with the pace of that shift differing more within villages than between them (Epstein et al., 2018). Although the Nepalese evidence concerns production choices rather than land prices directly, it is consistent with capital and expectations being redirected toward the land categories most capable of generating returns after a shock — in the present sample, orchards and irrigated parcels. At the same time, farmland capitalization research shows that nominal prices respond to inflation, interest rates, credit conditions and development expectations as well as to farm income (Just & Miranowski, 1993; Deaton & Lawley, 2022). The estimates in Table 2 should therefore be read as statistically significant reported price changes, not as an isolated causal effect of the earthquakes.

Table 2. Reported Agricultural Land Prices Before and After the Earthquakes

Land type	Before earthquake (TRY/da)	After earthquake (TRY/da)	Change (%)	p-value
Irrigated land	394,395.93	1,046,222.49	165.27	<0.001
Dry land	334,358.02	745,679.01	123.02	<0.001
Orchard land	481,470.59	1,323,058.82	174.80	<0.001

Note: Values are nominal TRY/da. The p-values are from paired-samples t-tests comparing producer-reported prices before and after the earthquakes.

Factors associated with land-sale tendency

The binary logit estimates provide little evidence that the measured demographic and farm-structural characteristics were independently associated with land-sale tendency (Table 3). Education, farming experience, log farm size and perceived post-earthquake demand all had p-values well above 0.10. This pattern differs from pre-earthquake evidence in Türkiye, where education, farm size and financial conditions were associated with participation in agricultural land markets (Özdemir et al., 2022), and from studies in India and Kenya showing that credit access, household assets and shock-related losses shaped land-sale participation (Deininger et al., 2009; Musyoka et al., 2021). The contrast should not be read as a direct contradiction: the studies use different outcomes, samples and institutional settings, and a non-significant coefficient in the present model does not establish that a factor is generally unimportant.

A similar overriding of conventional demographic predictors by disaster-specific variables has been reported elsewhere: in rural Sichuan, the intensity of a household's earthquake risk perception, rather than its farm size or age, was the strongest correlate of a shift away from agricultural livelihoods (Zhou et al., 2021), and in Bangladesh, repeated disaster exposure — not baseline household characteristics alone — predicted subsequent movement out of agriculture (Gray & Mueller, 2012). The present findings therefore sit within a wider pattern in which acute disaster exposure temporarily outweighs the structural variables that ordinarily organize land and labour markets in agriculture.

Age was negatively associated with the outcome at the 10% level ($\beta = -0.026$, $p = 0.066$). Its odds ratio of 0.974 corresponds to an estimated 2.6% reduction in the odds of the coded sale outcome for each additional year of age, holding the remaining variables constant. This result is marginal and should not be treated as conventionally significant. It nevertheless accords with the wider view that age and the farm household life cycle can enter decisions about remaining in agriculture, although their direction and magnitude depend on farm structure and financial conditions (Türkekul & Abay, 2024).

The indicator capturing whether the earthquake affected the respondent's sale decision was the only covariate associated with the outcome at the 5% level ($\beta = -1.735$, $p = 0.004$). Its odds ratio was 0.176, implying odds that were 82.4% lower for the category coded 1 than for the reference category, conditional on the other covariates. The statistical prominence of this indicator is contextually consistent with evidence that the earthquakes changed production, employment, mobility and working conditions in the four provinces (Aydın Can et al., 2024; Dinçer et al., 2024; International Labour Organization & International Organization for Migration, 2024). It does not, however, resolve the direction of the behavioural response. That direction depends on how the questionnaire response and its reference category were coded; because the coding was not available in the analytical documentation, the coefficient cannot safely be translated into a claim that the earthquake either increased or reduced producers' propensity to sell.

Table 3. Binary Logit Estimates for Land-Sale Tendency

Variable	Coefficient (β)	Std. error	Odds ratio	p-value
Age	-0.026	0.014	0.974	0.066
Education	-0.049	0.040	0.953	0.220
Farming experience	0.006	0.014	1.006	0.650
Farm size (log)	-0.007	0.111	0.993	0.946
Post-earthquake demand	0.033	0.316	1.034	0.917
Earthquake effect on decision	-1.735	0.606	0.176	0.004

Note: The dependent variable is land-sale tendency (1 = tendency to offer land for sale; 0 = otherwise). Odds ratios are exp(β). The interpretation of the post-earthquake demand and earthquake-effect indicators is conditional on the questionnaire coding and reference categories.

Taken together, the results point to two distinct dimensions of post-earthquake land-market adjustment. Reported nominal values increased across land types, with the strongest proportional change in orchards, whereas individual sale tendency was not systematically differentiated by education, experience, farm size or perceived demand in the fitted model. The earthquake-related decision indicator carried the clearest statistical signal, but its substantive direction must remain provisional until the original coding is verified. Model-fit statistics were not available, which limits assessment of the logit's overall explanatory performance. Read against comparative evidence from other post-disaster agricultural economies, neither dimension looks like an anomaly specific to this sample; both look like features that recur wherever a major earthquake disrupts a farming region. The Discussion section develops this comparison, and its policy implications, in more detail.

DISCUSSION AND RESULTS

Post-earthquake repricing of agricultural land

The findings reveal an adjustment that is easy to misread if prices and producer behaviour are considered separately. Reported nominal values rose markedly for every land type, yet the regional economy was simultaneously coping with damaged infrastructure, interrupted production, labour displacement and constrained access to inputs and markets. Agricultural land therefore did not behave simply as an asset whose value fell in proportion to physical disruption. It continued to embody productive capacity, household wealth and expectations about future use. In a reconstruction economy, those expectations can be pulled in opposing directions: impaired farm income and greater uncertainty may depress value, while inflation, scarcity, relocation, infrastructure investment and demand for non-agricultural uses may raise it. This combination is consistent with the capitalization literature, which treats farmland prices as the outcome of expected agricultural returns together with credit conditions, macroeconomic variables and development expectations (Just & Miranowski, 1993; Plantinga et al., 2002; Deaton & Lawley, 2022). A systematic review of this literature reaches a similar conclusion from a different angle: intrinsic parcel attributes and extrinsic macroeconomic and policy conditions are consistently found to act jointly rather than separately, and hazard exposure is itself one of the extrinsic conditions capitalized into price, sometimes positively and sometimes negatively depending on its severity and persistence (Agosta et al., 2025).

The magnitude and ordering of the reported changes are also informative. Orchard values increased by 174.80%, irrigated-land values by 165.27% and dry-land values by 123.02%. The higher proportional changes for orchards and irrigated land may reflect the scarcity of productive sites, embedded perennial investment, access to water and expectations of future income. They may also reflect their attractiveness for uses unrelated to farming. Evidence from other land markets shows that productive attributes and proximity to infrastructure are capitalized alongside the prospect of development (Plantinga et al., 2002; Nilsson & Johansson, 2013). The present data cannot assign a separate weight to these channels. The defensible conclusion is narrower but still important: the post-earthquake repricing was not uniform, and the strongest increases occurred in land categories with relatively high productive and investment value. A structurally similar reallocation toward higher-value production has been documented after other major earthquakes: in Nepal, the 2015 Gorkha earthquake accelerated an existing shift among smallholders from subsistence toward cash-crop farming (Epstein et al., 2018), consistent with capital and expectations being redirected toward the categories of land — orchards and irrigation — capable of generating higher returns after a shock.

This pattern differs from the straightforward disaster discount often found in residential property studies. Following major earthquakes in Japan, newly salient risk was reflected in lower relative housing values in exposed locations (Naoi et al., 2009). After the 2023 earthquakes, seismic risk and building age also became more strongly capitalized in Istanbul's housing market (Çepni et al., 2026). The increase observed in the present study does not invalidate that literature. Agricultural land is a different asset, the estimates are nominal, and the study area was affected not only by risk reassessment but also by reconstruction demand, displacement and severe price inflation. Without an unaffected comparison area and transaction-level observations, it is not possible to determine whether the same parcels would have appreciated even more or less in the absence of the earthquakes. The direction of the present result also contrasts with transaction-level evidence from Taiwan, where agricultural disaster-relief payments were capitalized negatively rather than positively into affected farmland, particularly in peri-urban parcels valued for conversion (Lee et al., 2021). Reconciling the two findings is speculative given the differences in hazard, country and outcome measured, but a plausible explanation is that Türkiye's high general inflation and the scale of reconstruction and displacement in the four provinces pushed nominal land values upward even where the underlying productive risk was being repriced downward — two effects that a single reported nominal price cannot separate. Evidence from Tokyo after the 2011 earthquake reinforces the need for such caution: even in a real-estate market far from the epicentre, price responses to newly salient seismic risk were selective across submarkets rather than uniform, so neither a rise nor a fall in reported nominal prices can, by itself, be read as evidence that risk was or was not being priced (Mikawa, 2025).

The distinction between land prices and agricultural recovery is therefore fundamental. Rising land values can strengthen the balance sheet of owners and expand the collateral value of their property.

They do not necessarily indicate that farming has become more profitable or that damaged enterprises have recovered. On the contrary, higher purchase prices can make expansion more difficult for active producers, increase the entry barrier for younger farmers and widen the gap between landowners and tenants. In a region where irrigation systems, storage, livestock facilities, processing capacity and market links were disrupted, an increase in asset value may coexist with a deterioration in the cash flow generated by that asset (Food and Agriculture Organization of the United Nations, 2023b; Presidency of the Republic of Türkiye, Presidency of Strategy and Budget, 2023). Treating land-price appreciation as evidence of rural recovery would therefore be misleading.

Land-sale tendency as a post-disaster adjustment

The logit results point to a second, related feature of the adjustment. Education, farming experience, log farm size and perceived post-earthquake demand were not independently associated with land-sale tendency at conventional levels of statistical significance. Age provided only marginal evidence. This differs from pre-earthquake findings in Türkiye, where farm size, education, indebtedness and participation in agriculture were linked to land-market behaviour (Özdemir et al., 2022), and from evidence in India and Kenya showing that losses, household assets, access to finance and local conditions shaped distress sales (Deininger et al., 2009; Musyoka et al., 2021). The difference is plausible. A disaster of this scale can temporarily reorder the hierarchy of household decisions, making immediate housing needs, debt, displacement, production losses and uncertainty more influential than characteristics that usually structure land-market participation. Qualitative evidence from Nepal after 2015 illustrates the mechanism: households lacking adequate external support resorted to selling productive assets, including livestock and, in some cases, land, a response the literature treats as a marker of vulnerability rather than an ordinary market transaction because it compounds the very fragility it is meant to relieve (Karki et al., 2022).

The statistical prominence of the earthquake-related decision indicator supports that interpretation, but it must be handled with discipline. The coefficient was significant and substantially larger in magnitude than those of the other covariates. Nevertheless, the original response coding and reference category were not available. The odds ratio therefore establishes a sharp difference between the coded categories; it does not establish whether earthquake influence raised or lowered sale tendency in substantive terms. This is more than a technical qualification. Reversing the coding would reverse the verbal interpretation while leaving the underlying model estimate unchanged. Any policy claim about the direction of the earthquake effect should consequently wait until the questionnaire codebook and analytical dataset are reconciled.

The absence of a significant coefficient for perceived post-earthquake demand should be interpreted with similar care. It does not show that reconstruction or relocation demand played no role in the land market. The price results indicate substantial market movement, while the demand variable captures an individual survey response and enters a model of sale tendency rather than price. Demand may affect the level of prices without independently distinguishing which producer is inclined to sell. It may also vary within provinces, districts and land types in ways that a single indicator cannot represent. The findings therefore suggest a separation between market-level repricing and household-level sale decisions, not the absence of a demand response.

This separation helps explain why higher prices and financial vulnerability can coexist. For a household facing damaged housing, interrupted production or debt, a more valuable parcel offers liquidity precisely when retaining it may be most important for future income. Research on shock-related land sales shows that access to banking and finance can moderate the need to dispose of land after adverse events (Deininger et al., 2009). The policy concern is thus not every sale. Voluntary transactions can improve farm structure and allow households to reallocate assets. The concern is a sale undertaken under acute pressure, before productive capacity and credit access have recovered, because such a transaction may convert a temporary liquidity problem into a permanent loss of agricultural income.

International lessons for post-disaster agricultural land governance

Comparative evidence from other seismically active countries offers concrete guidance for translating these findings into policy. Japan has the longest institutional experience with reconciling reconstruction with land tenure.

Its land-readjustment mechanism, first codified for agricultural consolidation in 1899 and later adapted for urban reconstruction after the 1923 Great Kanto earthquake, allows authorities to reorganize fragmented or damaged holdings and relocate communities to safer ground while compensating owners through revised plot allocations rather than expropriation or forced sale (Yanase, 2018). The same instrument was used after the 2011 Great East Japan earthquake to move coastal settlements to higher ground without severing owners from equivalent replacement parcels. Because the mechanism preserves ownership continuity even as it changes plot boundaries, it offers a template for the concern raised in the present study: that reconstruction in Adıyaman, Hatay, Kahramanmaraş and Malatya could otherwise absorb productive orchards and irrigated parcels into unplanned settlement. A separate strand of Japanese evidence is nevertheless a caution against assuming that markets alone register risk appropriately: transaction data from Tokyo show that price responses to the 2011 earthquake were selective and geographically uneven even in a market far from the epicentre, with risk perception affecting some submarkets while leaving others largely unpriced (Mikawa, 2025). Reconstruction-zone land markets, including the one examined here, cannot therefore be assumed to self-correct for risk without the active monitoring proposed below.

Chile's recovery from the 2010 Maule earthquake and tsunami illustrates the risk of prioritizing reconstruction speed over land-use discipline. National authorities issued rebuilding subsidy vouchers that allowed households to reconstruct quickly, but the pace of disbursement outstripped local planning capacity in several affected municipalities, and reconstruction proceeded in some locations before hazard mapping, land-use plans and tenure questions had been resolved (Siembieda et al., 2012). This experience is directly relevant to the recommendation, developed below, that irrigated and orchard land be mapped and protected before reconstruction approvals are granted: without that sequencing, speed and the protection of the most productive agricultural land are not automatically compatible objectives, and a purely demand-led approach to reconstruction finance can foreclose more deliberate land-use choices.

The clearest cautionary case comes from China's reconstruction after the 2008 Wenchuan earthquake, when authorities relocated large numbers of rural households into concentrated settlements to rebuild housing more efficiently. Evaluations of these settlements found that many resettled farmers ended up physically separated from their contracted farmland, that renegotiating access to land near the new settlements proved administratively costly, and that living costs rose by roughly half relative to dispersed villages without a matching increase in agricultural income, pushing part of the resettled population out of farming altogether (Peng et al., 2018). Household-level analysis from the same region later found that the strength of a household's earthquake risk perception, more than its farm size or demographic profile, predicted a shift toward non-farm livelihoods (Zhou et al., 2021) — a pattern that parallels the present study's own finding that an earthquake-related indicator, not age, education or farm size, carried the clearest statistical association with land-sale tendency. Read together, the Sichuan and Kahramanmaraş evidence both suggest that post-earthquake land-market and livelihood adjustment is driven less by the stable characteristics that ordinarily structure rural land markets than by the disaster experience itself, and that reconstruction planning which relocates people without preserving practical access to productive land can convert a temporary disruption into permanent farm exit.

Nepal's experience after the 2015 Gorkha earthquake shows that recovery support calibrated only to income or asset loss can miss important heterogeneity among affected smallholders. Even within villages that appeared demographically similar, recovery outcomes differed more within groups than between them, and the disaster accelerated an existing shift from subsistence to cash-crop production among households with the resources to make that transition, while poorer households relied more heavily on common resources and community institutions such as forest and savings groups (Epstein et al., 2018). Complementary evidence indicates that where such support was absent, some households resorted to selling productive assets, a step that can compound future vulnerability precisely because it removes the means of recovery (Karki et al., 2022). Applied to the present findings, this suggests that assistance targeted only at demographic categories, or only at restoring cash income, risks overlooking both the smallholders best placed to intensify production if supported and those whose asset sales during the acute recovery period would be most damaging in the long run.

A further, more directly actionable lesson concerns land tenure documentation itself.

Evidence from rural Ethiopia shows that formal land certification cushioned households against weather shocks: certified households experienced a food-consumption decline of roughly one percentage point after a shock, compared with about 25 percentage points in uncertified villages, an effect that operated mainly through improved access to credit and informal assistance and that was largest for smallholders rather than large landowners (Solomon & Kijima, 2022). The Ethiopian evidence concerns weather shocks rather than earthquakes, but the underlying mechanism — secure, legible title reducing the need for outright sale when a shock hits — applies directly to the Kahramanmaraş provinces, where accelerating cadastral clarification and deed registration through the General Directorate of Land Registry and Cadastre could plausibly reduce distress-driven land loss without requiring new compensation spending.

Finally, the Taiwanese finding that agricultural disaster-relief payments were capitalized negatively into farmland prices (Lee et al., 2021) is a reminder that recovery finance in the present study area should be evaluated for its effect on land values, not only on farm income; if future monitoring finds that recovery funds are instead being capitalized into land prices, as the scale of nominal appreciation reported here might suggest, the appropriate response is not necessarily to withhold support but to pair it with the land-market disclosure proposed below. Cross-country evidence on agricultural insurance points in a complementary direction: adequately subsidized agricultural insurance has measurably reduced households' need to liquidate productive assets after a shock in several developing- and middle-income-country settings, although uptake typically remains low without public premium subsidy or bundling with credit, and basis risk continues to limit reliability in some contexts (Kramer et al., 2022). Türkiye already operates a state-supported agricultural insurance pool, TARSİM, whose crop, orchard, greenhouse, livestock and aquaculture products include earthquake as a standard insured peril; the cross-country evidence on uptake and bundling therefore points to a narrower but concrete question for the earthquake-affected provinces — whether enrolment, premium-subsidy targeting and claims-processing speed under TARSİM were adequate in Adıyaman, Hatay, Kahramanmaraş and Malatya before and immediately after February 2023, and whether faster, higher-coverage claims settlement in earthquake-declared districts could reduce the liquidity pressure that appears to be driving reported sale tendency in the present sample.

Implications for agricultural recovery

The results place agricultural land governance near the centre of post-earthquake recovery. The wider earthquake-affected region accounted for an important share of Türkiye's agricultural production, and official assessments document extensive damage to planted areas, rural infrastructure and farm assets (Food and Agriculture Organization of the United Nations, 2023a, 2023b; Presidency of the Republic of Türkiye, Presidency of Strategy and Budget, 2023). If the most productive land is absorbed by unplanned settlement or speculative development, restoring irrigation, roads and processing capacity will not by itself restore the pre-disaster production base. The strong increases reported for orchards and irrigated land make this risk particularly salient because both categories depend on long-term investment that cannot be recreated quickly in another location. Comparative experience reviewed above shows that this risk materializes precisely when reconstruction speed is prioritized without a parallel land-use safeguard (Peng et al., 2018; Siembieda et al., 2012), and that it can be mitigated, as in Japan, when relocation is organized through plot reallocation rather than expropriation (Yanase, 2018).

Recovery policy must also distinguish between asset wealth and operating liquidity. A farmer may own land whose market value has increased while lacking the cash required to repair a well, replace machinery, replant an orchard or finance the next production cycle. Credit decisions based only on collateral value may miss this distinction. Conversely, broad support based solely on demographic categories may overlook enterprises with severe damage and weak cash flow. The non-significance of age, education and farm size in the fitted model does not prove that these variables never matter; it indicates that they are insufficient, on their own, for identifying post-earthquake sale tendency in this sample. Damage, income interruption, debt exposure, displacement, irrigation access and the time required to restore production are more direct criteria for targeting recovery assistance.

Study limitations and research priorities

Several limitations define the boundary of the conclusions. First, the price measures are retrospective reports collected in a cross-sectional survey.

Recall error and differences in respondents' knowledge of local transactions may affect the estimates. Second, the values are nominal and cannot distinguish earthquake-related repricing from inflation or wider asset-price movements. Third, the design lacks a contemporaneous unaffected control group and independently observed parcel transactions; the paired tests consequently identify reported temporal differences, not a causal earthquake effect. Fourth, broad land categories conceal differences in soil quality, water reliability, distance to markets, damage intensity and development pressure. Fifth, the coding documentation for the earthquake-related indicators and standard model-fit statistics were unavailable, limiting substantive interpretation and assessment of predictive performance.

These limitations do not remove the study's contribution. The survey provides evidence from 271 agricultural enterprises in four severely affected provinces, separates irrigated land, dry land and orchards, and examines price adjustment alongside producer sale tendency. Few post-disaster property studies combine these two dimensions, and fewer still focus on agricultural land. The next step should be a panel design that follows the same enterprises over time and links their responses to verified deed transactions, geocoded damage, irrigation access and subsequent land use. Nominal prices should be deflated, comparable unaffected districts should be included, and buyer identity should be recorded to determine whether land is moving between farmers or towards non-agricultural actors. Qualitative interviews would also help distinguish planned portfolio adjustment from distress-driven sale. Finally, future models should retain complete codebooks, report sample size and diagnostics for each specification, and test province- and land-type-specific effects rather than assuming a uniform regional process.

Policy priorities for agricultural recovery

The study shows that the agricultural land market was an active part of post-earthquake adjustment rather than a passive reflection of physical damage. Producer-reported nominal prices more than doubled across irrigated land, dry land and orchards, with the largest proportional increase in orchards. At the same time, stable socioeconomic characteristics did not explain land-sale tendency in the estimated model as clearly as the earthquake-related decision indicator. The evidence does not support a simple narrative in which the disaster uniformly reduced land values or in which one type of producer was consistently driven to sell. It points instead to a market shaped by productive scarcity, macroeconomic conditions, reconstruction demand and household liquidity needs operating at the same time.

Four policy priorities follow from this evidence. First, post-disaster land-market monitoring should become routine. The Ministry of Agriculture and Forestry, the General Directorate of Land Registry and Cadastre, municipalities and provincial authorities should combine deed transactions, rents, declared land use and conversion permits in a district-level monitoring system. During the recovery period, quarterly reporting should distinguish irrigated land, dry land and orchards; separate asking prices from completed transactions; and record whether buyers remain engaged in agriculture. This would make unusual price acceleration, concentration of purchases and conversion pressure visible before they become irreversible. Comparative evidence indicates that such documentation would not only be diagnostic: in rural Ethiopia, formal land certification independently cushioned the welfare impact of shocks — mainly by improving access to credit and community assistance, with the largest protective effect for smallholders rather than large landowners (Solomon & Kijima, 2022) — so accelerating cadastral clarification and deed registration in the earthquake-affected districts could plausibly serve a protective as well as a monitoring function.

Second, reconstruction planning should explicitly protect high-value agricultural land. Irrigated parcels and established orchards should be mapped before new residential, industrial or temporary-settlement areas are approved. Where feasible, reconstruction should be directed towards sites with lower agricultural opportunity cost, and any conversion of productive land should require a transparent assessment of its effect on irrigation networks, farm access and regional food production. Protection must be accompanied by investment: repairing irrigation, rural roads, storage and processing facilities is necessary if productive land is to retain its agricultural use rather than merely its asset value.

Third, recovery finance should reduce the need for distress-driven sales. Time-limited working-capital loans, partial credit guarantees, debt restructuring and targeted grants for damaged irrigation systems, machinery and perennial crops should be tied to verified damage and recovery plans.

Insurance and compensation payments should be processed rapidly enough to arrive before households are forced to liquidate productive assets. These measures should have clear eligibility rules and sunset dates; their purpose is to bridge a disaster-related liquidity gap, not to prevent voluntary land transactions or freeze the market. Türkiye already operates a state-supported agricultural insurance pool, TARSİM, whose crop, orchard, greenhouse, livestock and aquaculture products include earthquake as a standard insured peril; a comparatively low-cost step would be to audit enrolment rates, premium-subsidy targeting and claims-processing speed in Adıyaman, Hatay, Kahramanmaraş and Malatya, and to expedite settlement in earthquake-declared districts. Cross-country evidence on agricultural insurance in developing and middle-income settings indicates that adequately subsidized coverage can measurably reduce reliance on distress asset sales after a shock, although uptake typically remains low without subsidy or bundling with credit, and basis risk continues to limit reliability in some contexts (Kramer et al., 2022); these are the same conditions — subsidy, bundling and reliable claims settlement — that will determine whether TARSİM coverage reaches producers before, rather than after, a land sale.

Fourth, assistance and evaluation should be based on observed exposure rather than simple demographic proxies. Damage to farm assets, loss of operating income, debt service, displacement, irrigation failure and stated sale pressure should be recorded together. Follow-up surveys should use stable variable definitions, preserve the full coding scheme and be linked—under appropriate confidentiality safeguards—to parcel and transaction data. Such a system would allow public support to be adjusted as recovery progresses and would provide the evidence needed to determine whether rising land values are financing reconstruction, excluding active farmers or accelerating conversion to non-agricultural use.

The central policy objective is not to suppress the land market. It is to ensure that short-term necessity does not produce avoidable farm exit, that reconstruction does not consume the region's most productive land, and that price signals can be distinguished from genuine recovery in agricultural income and capacity. In the earthquake-affected provinces, the durability of rural recovery will depend not only on rebuilding what was damaged, but also on who retains access to land, how that land is used and whether producers have enough financial room to remain in agriculture while local markets adjust. Where reconstruction and the protection of productive land appear to conflict, international experience shows the tension is not absolute: Japan's land-readjustment approach, developed originally for agricultural consolidation and repeatedly adapted for post-earthquake reconstruction, reorganizes and relocates holdings through revised plot allocation rather than expropriation, allowing rebuilding to proceed without severing farmers from land they can continue to work (Yanase, 2018). Adapting that principle — protecting continuity of access to land, not merely its nominal ownership — may prove as important for southern Türkiye's agricultural recovery as any single financing or monitoring instrument proposed above.

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DOĞANIN ENDÜSTRİLEŞMESİ: MANZARA RESMİNİN ESTETİK DÖNÜŞÜMÜ[42]

THE INDUSTRIALIZATION OF NATURE: THE AESTHETIC TRANSFORMATION OF LANDSCAPE *PAINTING*[43]

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ÖZET

Bu çalışma, Endüstri Devrimi'nin yarattığı radikal sosyo-ekonomik ve mekânsal değişimlerin, görsel sanatlardaki en belirgin yansımasını manzara (landscape) resmi üzerinden incelemeyi amaçlamaktadır. 18. yüzyılın sonlarından itibaren hız kazanan sanayileşme hamleleriyle birlikte, insan ile doğa arasındaki ilişki kökten bir kırılma yaşamış ve bu süreç yeryüzünde kalıcı izler bırakan Antroposen Çağ'ın kapılarını aramıştır. Bu dönüm noktasıyla birlikte el değmemiş, idealize edilmiş pastoral doğa algısı, yerini makinelerin, fabrikaların ve kentleşmenin dönüştürdüğü mekanize bir gerçekliğe bırakmıştır. Yaşanan bu ekolojik ve mekânsal kırılma, sanatçıların doğayı yalnızca tematik olarak değil, estetik ve felsefi olarak da yeniden yorumlamasına neden olmuştur.

Bildiride, doğanın endüstrileşme süreciyle birlikte manzara resminde yaşanan dönüşümler analitik bir yöntemle ele alınmaktadır. Süreç içinde yeşil alanların yerini alan fabrika bacaları, gökyüzünü kaplayan is ve duman, kırsalı bölen demiryolları gibi unsurların kompozisyonlara nasıl dâhil olduğu; ışık, renk, doku ve mekân kurgusunda ne tür estetik dönüşümlere yol açtığı dönemin nitelikli eserleri üzerinden çözümlenmektedir. Romantizmden İzlenimciliğe uzanan bu çizgide, endüstrileşmenin getirdiği hız ve yapay ışık gibi kavramların, manzara resmini modern sanatın biçimsel dillerine nasıl yaklaştırdığı tartışılmaktadır. Teorik düzlemde ele alınan bu görsel dönüşüm, aynı zamanda pratik sanatsal uygulamaların plastik dili üzerinden de değerlendirilmektedir. Sonuç olarak çalışma, manzara resminin geçirdiği evrimin, sadece bir üslup değişimi değil, doğanın endüstrileşmesiyle değişen insanlık hafızasının ve görsel algının doğrudan bir sonucu olduğunu ortaya koymaktadır.

Anahtar Kelimeler: Manzara Resmi, Endüstri Devrimi, Estetik Dönüşüm.

ABSTRACT

This study aims to examine the radical socio-economic and spatial changes brought about by the Industrial Revolution through their most prominent reflection in the visual arts: landscape painting. With the acceleration of industrialization movements from the late 18th century onward, the relationship between humanity and nature underwent a fundamental rupture, ushering in the Anthropocene Epoch, which has left permanent traces on the Earth. Following this turning point, the untouched, idealized perception of pastoral nature gave way to a mechanized reality transformed by machines, factories, and urbanization. This ecological and spatial rupture led artists to reinterpreting nature not only thematically but also aesthetically and philosophically.

In this paper, the transformations that occurred in landscape painting alongside the industrialization of nature are analyzed through an analytical method. It examines how elements such as factory chimneys replacing green spaces, soot and smoke engulfing the sky, and railways dividing the countryside were integrated into compositions, and what kinds of aesthetic transformations they induced in the configuration of light, color, texture, and space through the prominent works of the period.

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Along this trajectory spanning from Romanticism to Impressionism, the paper discusses how concepts brought by industrialization, such as speed and artificial light, brought landscape painting closer to the formal languages of modern art. This visual transformation, addressed on a theoretical level, is also evaluated through the plastic language of practical artistic applications. Consequently, the study reveals that the evolution of landscape painting is not merely a stylistic change, but a direct consequence of shifting human memory and visual perception shaped by the industrialization of nature.
Keywords: Landscape Painting, Industrial Revolution, Aesthetic Transformation.

GİRİŞ

Manzara resmi, insanlık tarihi boyunca doğanın ve insanın çevresiyle kurduğu ilişkinin sanat içerisindeki önemli göstergelerinden biri olmuştur. Yeryüzü, gökyüzü, deniz, ağaçlar, doğal oluşumlar, kentsel yapılar ve tarihi alanlar, farklı dönemlerde sanatçıların temel konuları arasında yer almıştır. Doğanın bu unsurları, manzara resminin temel bileşenlerini oluşturmuş ve tarihsel süreç içerisinde farklı biçimlerde yorumlanmıştır (Tandırlı, 2004: 306).

Manzara resminin gelişimi incelendiğinde, doğanın zaman içinde düşünsel ve toplumsal koşullarına bağlı olarak değiştiği görülmektedir. Orta Çağ'da günlük yaşam ve dinsel anlatılar içerisinde yer alan doğa, Rönesans döneminde bilim ve aklın önem kazanmasıyla daha ayrıntılı biçimde gözlemlenmeye başlanmıştır. Barok dönemde gökyüzü, uzaklık, ışık ve biçimsel zenginlik ön plana çıkarken, 18. yüzyılın sonlarında bilimsel ve teknolojik gelişmelerin hız kazanması, doğanın ve insanın konumunu yeniden şekillendirmiştir. Bu dönüşümün önemli eşiklerinden biri Endüstri Devrimi'dir. Mekanize güçlerin ve sanayileşmenin ortaya çıkardığı toplumsal değişimler, insanın doğayla kurduğu ilişkiyi yeniden biçimlendirmiştir. Sanayileşmeyle birlikte kapitalist üretim düzeninin doğa üzerindeki hâkimiyeti artmış, doğal kaynakların yoğun kullanımı çevresel tahribatın önemli nedenlerinden biri hâline gelmiştir. Bu süreç, insanın egemen olduğu Antroposen Çağı'nı ortaya çıkarmıştır. Bu durum, Antroposen kavramı bağlamında insan faaliyetlerinin doğal çevre üzerindeki belirleyici ve dönüştürücü etkisinin tarihsel gelişimi açısından değerlendirilebilir.

Bu çalışmanın amacı, Endüstri Devrimi'yle tahribata uğrayan doğanın sanat eserlerindeki görünümünü incelemek ve sanatın bu dönüşüm karşısındaki tavrını tarihsel bir perspektiften ortaya koymaktır. Çalışmanın temel problemi, manzara resminin farklı dönemlerde hangi koşullar altında değişim gösterdiği ve Endüstri Devrimi'nin manzara resmi üzerinde nasıl bir etki oluşturduğudur. Çalışmada nitel veri toplama yöntemi kullanılmış; kitap, tez, makale ve görsel kaynaklardan elde edilen veriler betimsel olarak yorumlanmıştır.

Manzara Resminin Tarihsel Değişimi

Resim sanatına konu olan manzaralar tarih boyunca her dönemde sanatçılar tarafından ele alınarak işlenmiştir. İlk çağlarda mağara duvarlarına yapılan resimlerden günümüze dek anlatılacak bu süreç yeni yöntem ve tekniklerle zaman içinde dönüşüme uğrayarak birçok sanat akımı ve sanatçı tarafından yorumlanmıştır (Timuçin, 2019: 413). Örneğin Orta Çağ'da takvimler için avlanma, ekin ekme ve toplama uğraşlarını ele alan manzara resimlerine benzer çalışmalar yapılmıştır. Rönesans döneminde bilim ve aklın öne çıkmasıyla doğaya yönelik gözlem ve incelemeler hız kazanmış, sanatçılar doğanın ayrıntılarını resimlerine daha yoğun biçimde aktarmaya başlamışlardır (Gombrich, 2002:218). Leonardo da Vinci'nin doğaya yönelik gözlemleri, bu yaklaşımın önemli örneklerinden biri olarak değerlendirilebilir. Rönesans sanatında doğanın ayrıntılı biçimde ele alınması, doğa imgesinin bağımsız bir görsel araştırma alanına dönüşmesinde etkili olmuştur (Boynukalın, 2017: 1319-1335).

Barok dönemde ise gökyüzü, uzaklıklar, atmosfer ve biçimsel zenginlik, manzaranın temel unsurları hâline gelmiştir. Doğa giderek resim sanatının ana konusu olmaya başlamış ve manzara resmi kendi başına bir ifade alanı kazanmıştır (Berger, 2002: 105). Barok dönemi ressamlarından Peter Paul Rubens'in manzara çalışmaları bu dönüşümün örnekleri arasında değerlendirilebilir (Eroğlu, 2007: 296). Jan Van Goyen'in çalışmalarında ise idealize edilmiş manzaranın yerine sıradan kırsal yaşamın ve doğal çevrenin sade görünümleri ön plana çıkmıştır (De Rynck, 2016: 301).

18. yüzyılın sonlarına gelindiğinde bilim ve teknolojideki gelişmeler insanı giderek merkeze taşımıştır. Bu dönemde Endüstri Devrimi'nin etkisiyle mekanize güçler karşısında hissedilen çaresizlik ve toplumsal bozulmalar sanatın konusu hâline gelmiştir.

Romantizm akımı içerisinde doğaya yeniden yönelme eğilimi güçlenmiş, doğa insanın karşısında güçlü ve yüce bir varlık olarak ele alınmıştır (Farthing, 2010: 268). Akım, Avrupa geneline yayılmış; İngiltere'de William Blake, Turner ve Constable fırtınalı doğa sahneleriyle hayranlık ve korkuyu işlerken, Fransa'da Delacroix ve Géricault, Almanya'da ise Caspar David Friedrich öne çıkan ressamlar olmuştur. Doğallığa ve özgürlüğe yönelen Romantikler, yerleşik yaşam biçimlerine karşıt yeni bir ifade alanı oluşturmuş, duygularını temel yaşam kaynağı edinmişlerdir (Şenyapılı, 2004: 4-6).



Resim 1: J.M.W. Turner, "Yağmur, Buhar ve Hız: Büyük Batı Demiryolu, 1844.

Resim sanatında 19. yüzyılda Fransız ressam Gustave Courbet ile başlayan Realizm, 19. yüzyılın sonlarında gerçeği olduğu gibi yansıtmayı hedefleyen ressamların varlığıyla ortaya çıkmıştır. İdealist yaklaşımın aksine olanı objektif bir dil ile aktaran gerçekçilik; Romantizm karşısında ise düşe, tinsele ve yaşanan anın özgür verilerine değer vererek var olan kalıpların dışına çıkmıştır. Bilimlerin gelişimi ve 1840-1842 yıllarında Auguste Comte'un geliştirdiği pozitivist felsefenin doğuşu, nesnel bir bakış benimseyen Realistlerin gerçeği olduğu gibi yansıtma arayışını desteklemiştir www.lebriz.com (06.06.2022). Fransız Devrimi'nin burjuvaziye iktidar yolunu açması ve bu dönemde emekçinin zanaatçının yerini almasıyla resim sanatında dinsel ve edebi konuların yerini iş ve işçilik temaları almıştır (İnankur, 1997: 53). Klasisizmden Romantizme ve ardından Realizme uzanan süreçte sanatçılar sosyo-politik olguları işlerken kendi toplumsal sınıfını bulmak istemiş; bu başkaldırının odağında da Gustave Courbet'nin gerçekçiliği yer almıştır (Bulut, 2018: 10).

19. yüzyılın ikinci yarısında Endüstri Devrimi ile bilim, teknoloji ve kitle iletişim araçlarında yaşanan büyük gelişmeler toplum yaşamında değişimlere ve bunalımlara yol açmıştır (Hauser, 1984: 351). Bu hızlı değişim duygusu resimde görüneni olduğu gibi yansıtmayı hedefleyen "Natüralist" anlayışı sarsmış ve Empresyonizm akımının ortaya çıkmasına zemin hazırlamıştır (Serullaz, 1991: 7). Natüralizmin gerçekliğine duyum ve optik deneyleri ekleyen Empresyonistler için amaç varlıkların anlık geçici görünüşlerini yakalamak olmuştur (Tansuğ, 1992: 236). Fotoğrafın icadı, prizmatik renklerin kullanımı ve Helmholtz ile Chevreul gibi fizikçilerin kuramları doğrultusunda atölye ışığı terk edilerek optik yasalara göre canlı bir doğa resmedilmeye başlanmıştır (Bayav, 2008; 25).

Metal tüp boyaların gelişmesiyle resim sanatı atölyelerin dışına taşarak halkın arasına girmiş ve açık havada çalışmak ressamlar için sıradan bir anlayış haline gelmiştir. Empresyonist sanatçılar kırlar ve bahçelerin yanı sıra kent yaşamının anlık görünümlerini de resimlerine konu etmişlerdir (Hauser, 2006: 84). Empresyonizmin önemli ressamlarından olan Monet, kent resimleri niteliğindeki "Saint-Lazare Garı" çalışmasında ise loş ışık altında lokomotiften çıkan buhar bulutlarının ışıkla olan dansını işlemiştir (Sönmez, 2016: 1159). Empresyonizmin renklere getirdiği bu bilimsel yaklaşım zamanla öteye taşınarak Neo-empresyonizm ve Sembolizm akımlarına zemin hazırlamıştır (Ayaydın, 2005: 94).



Resim 2: Claude Monet, "Saint-Lazare Garı", 75 x 104 cm., Tuval Üzerine Yağlı Boya, 1877.

Endüstri Devrimi'yle beraber teknolojinin önemli bir buluşu olan elektrik, hızın önemli bir göstergesi olmuştur. Bu durumun imgelere yansıyan karşılığı ise ilk kez Fütürist sanatçıların eserlerinde görülmüştür. Temalarını endüstriyel ve kentsel olanlardan seçen Fütüristler, devinim olarak yorumladıkları hız kavramına odaklanmışlardır. Grup üyelerinden Umberto Boccioni'nin Ruh Durumları: Uğurlamalar (1911) isimli üç panosu, bir tren istasyonunda vedalaşan insanların bazısı trenle uzaklaşırken, bazısı da evlerine dönerken gösterilmiştir. Bu durum teknolojiyi, hızı ve kirliliği göstermektedir. Resimde dönemin teknolojisinin önemli buluşlarından buharlı lokomotif ana figür olarak görülmektedir. Lokomotif formu, Kübist anlayışa uygun olarak resmin yüzeyine dağılmıştır. Çizgiler ve lokomotifin sağ kısmındaki bazı gölgeler vagonları, sol kısmındaki çizgiler ise elektrik direklerini belirtir ve doğa manzarası izlenimi meydana geldiği görülmektedir (Lynton, 1982: 90-91).



Resim 3: Umberto Boccioni, "Ruh Durumları: Uğurlamalar", 70 x 96 cm., T.Ü.Y.B 1911.

Sanayileşmeyle beraber kentsel yapılar, gelişen evler, sanayi ve doğa yapıları sanat eserlerinde iç içe geçmeye başlamıştır. Bu durumun en güzel örneğini sürrealist ressam Georgia O'Keeffe'de görülmektedir. Penceresiz, süssüz yapılar görkemli olduğu kadar, yalnızlığı da akla getirmektedir. Şehre konumlanan evlerin ufuk çizgisini yok ettiği, gökyüzündeki ay ışığını kapatarak aşağıdaki sokağın göze çarpan ışığını çevreleyen resme açısal gösterişli bir hava vermiştir (Melick, 2014: 138).



Resim 4: Georgia O'Keeffe, "New York'ta Ay", 122 x 76.2 cm, T.Ü.Y.B, 1925.

Endüstri Devrimi'nin başlamasıyla beraber teknoloji ve sanayideki değişimler, insanların yalnızca çalışma yaşamlarını değil, duygu ve düşünce yapılarında da devasa değişimler yaratmıştır. Tekniğin hızlı ilerlemesi, insanları üretim yapılan sahalara yöneltmiştir. Bu duruma bağlı olarak üretim artmış, aynı zamanda aşırı tüketim süreci meydana gelmiştir. Endüstrinin hizmetinde şekil alan yaşamla beraber insan yalnız kalmıştır. Endüstrileşmenin doğaya ve çevreye etkisinin yoğun olduğu bu ortamda sanat eserlerinde de özellikle sanatçıların ortaya koyduğu psikolojik ifadeler yer almaya başlamıştır (Şişman, 2006: 60-62). Bunalımlar, ruhsal sıkıntılar, içe kapanma durumları eserlere yansırken, manzara resimlerinin yerine her alanı kaplayan sanayi ürünleri almıştır ve bu endüstri manzaralarına dönüşmüştür. Sanayileşmenin etkisiyle hayatı biçimlendiren ve değiştiren gelişmeler, sanayi toplumunda insanın huzursuzluğu sanatçıların eserlerine yansımış ve yeni arayışları doğurmuştur.

Endüstri Devrimi ve Antroposen Çağ

Endüstri Devrimi, Avrupa'da 18. yüzyılın sonlarında başlayan ve 19. yüzyılın ortalarında hız kazanan ve yayılan, bilimsel buluşlar doğrultusunda teknolojik dönüşümlerin yaşandığı, "geleneksel el işi dünyasından makine ilkesine" geçiş evresidir (Ayas, 2018: 10). Bu dönemin yaşanmasında, 17. yüzyılda teknolojik yeniliklerle beraber tarımsal alanda yeniliğin yaşanması, ticaretin artış göstermesi, çalışan kesimin nüfus ve sosyal hareketlerdeki toplu ve hızlı değişimi etkili olmuştur. Ayrıca, yatırımcıların paralarını değerlendirmek için yeni alanlar araması, yatırım olanaklarının artması, enerji alanında yenilikçi yaklaşımların aranması büyük etken olduğu söylenebilir (Köklü, 2012: 4). Endüstri Devrimi'yle beraber yatırımcıların sermaye genişletmesi adına kentlerin düzensiz bir büyüme evresine girdiği görülmüştür. Kentleri yeni bina türleri, ambarlar, fabrikalar, ticaret büroları, ofisler, tren istasyonları sarmış bu yeni yapılar çağdaş sanayi döneminin ön sırada olan imgeleri haline gelmiştir (Hollingsworth, 2009: 436). Sermaye, teknoloji ve sanayileşme ekseninde gerçekleşen bu radikal dönüşüm, insanın doğa üzerindeki müdahale gücünü eşi benzeri görülmemiş bir boyuta taşımıştır. Üretim ve kentleşme baskısıyla yeryüzünün fiziki yapısının değiştirmesi, Homo Sapiens'in gezegensel ölçekte belirleyici bir güce dönüşmesine zemin hazırlamıştır. İşte insanoğlunun doğaya olan bu kitlesel müdahalesinin jeolojik bir boyuta ulaşması, litaretürde yeni bir çağın başlangıcı olarak kabul edilmektedir. Kelime anlamıyla Antroposen terimi iki kökü, "Antropos" ve "Kainos" köklerini oluşturur. Antropos; insan yüzlü olan, yukarıya bakan, Mainos; sadece yeni bir zaman birimi değil aynı zamanda yeni bir nitelik ya da biçim olan eklerle oluşturulmuştur (Wark, 2020: 302). Homo Sapiens'in jeolojik bir süper güç haline geldiği ve dünyanın uzun gelişiminde yeni bir yola girdiği zamanı anlatmaktadır. Antroposen, insanlık tarihinde, yaşam tarihinde ve dünya tarihinde bir dönüm noktasıdır. Yaşamın kronolojisinde yeni bir bölüm ve insan hikayesinin yeni bir bölümüdür (Levis ve Maslin, 2018: 5).

Endüstrileşmeyle birlikte kapitalist üretim anlayışının doğa üzerindeki hâkimiyeti artmış; doğal kaynakların yoğun kullanımı, üretim faaliyetleri ve çevre kirliliği doğal dengenin bozulmasına neden olmuştur. Böylece doğa, yalnızca insan yaşamının sürdürüldüğü bir çevre olmaktan çıkarak ekonomik üretimin ve tüketimin bir parçası hâline gelmiştir.

Bu dönüşüm sanatın doğayı ele alış biçimini de değiştirmiştir. Sanatçılar doğayı yalnızca estetik bir güzellik alanı olarak değil, insan müdahalesi sonucunda değişen, parçalanan ve tahrip edilen bir çevre olarak ele almaya başlamışlardır. Bu nedenle manzara resmi, Antroposen Çağ'da insan ve doğa arasındaki ilişkinin değişimini görünür kılan bir sanat alanı olarak değerlendirilebilir.

Çevresel Tahribatın Sanata Yansıması

20. yüzyılın ikinci yarısından itibaren çevresel sorunların daha görünür hâle gelmesiyle sanatçıların doğaya yönelik yaklaşımları da değişmiştir. İnsan faaliyetlerinin doğal çevre üzerindeki etkisinin artması; çevre kirliliği, doğal yaşam alanlarının yok olması, maden çıkarımı, kentleşme ve doğal kaynakların tükenmesi gibi sorunların sanatın konusu hâline gelmesine neden olmuştur. Bu durum, Antroposen Çağ'da sanatın çevresel sorunlara yönelik eleştirel yaklaşımını güçlendirmiştir. Sanatçılar, mühendisler, aktivistler doğayı temsil etmek yerine, insan müdahalesinin neden olduğu çevresel sorunları görünür kılmaya yönelmişlerdir.

Teknolojinin yarattığı farklı bakış açısı ile geleneksel yapıdan, tuvalden, bezden ve birçok sanat pratiğinde uzaklaşmışlardır. Bu durum yeni malzeme arayışını beraberinde getirmiştir. Bu kez sanat dili, geleneksel olanı hiçe sayan, avangart düşünceyi yansıtan özgürlükçü bir hareketle malzeme üzerine yoğunlaşırken daha ziyade kavram yani anlatılmak istenen düşünceye odaklanılmıştır (Karaçalı, 2018: 29-35).

Amerika'da yaşayan Macaristan doğumlu Agnes Denes'e göre kötü yönetim, dünyadaki açlık, atık ve ekolojik endişeler "gıda, enerji, ticaret ve de ekonomiyi" temsil etmektedir (Brown, 2014:12). Bu evrede sanatçıların doğrudan çevreye dikkat çekmelerinin sebebi modern hayatın oluşturduğu yıkımlar sonunda çevrenin ve doğanın tahrip olup bozulması üzerine düşünmek istemeleridir. Buna bağlı olarak modern hayattan geri durmaları söz konusu olmuştur.



Resim 5: Agnes Denes, "Wheatfield - A Confrontation, Buğday Tarlası-Bir Yüzleşme", 1982.

16. İstanbul Bienali kapsamında gerçekleştirilen "Yedinci Kıta" projesi plastik atıkların oluşturduğu çevresel tahribatı gündeme getirirken, Ozan Atalan'ın "Monokrom" adlı çalışması yapılaşma nedeniyle doğal yaşam alanlarının yok oluşuna dikkat çekmektedir. Ozan Atalan'ın 16. İstanbul Bienali için hazırladığı çalışma insanların yayılım faaliyetlerinin bedelini göz önüne almış ve uygarlığın sınırsızca büyümesiyle doğanın ortadan kalkması karşında bağlantı kurmuştur. "Monokrom 2019" isimli enstalasyon, İstanbul ve çevresindeki manda yaşam alanlarının yok olmasına vurgu yapmaktadır. Yeni İstanbul Havalimanı bu canlı türünün yaşam alanlarını kaybetmesine neden olmuştur. Atalan'ın enstalasyonunda, belgesel nitelikle bir video kayıt, mandaların Kemerburgaz'daki yaşam sahalarını ve inşaat sektörünün bu alanları nasıl yok ettiğini göstermektedir https://bienal.iksv.org (06.06.2022).



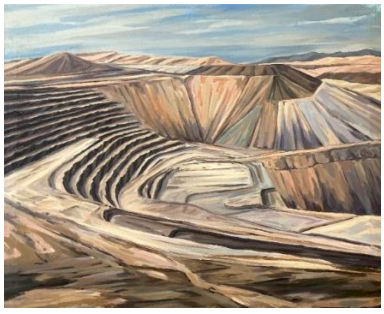
Resim 6: Ozan Atalan, "Monokrom", 2019.

Alper Aydın, "İyi Bir Komşu" adıyla düzenlenen 15. İstanbul Bienali'nde yer alan yerleştirmesi D8M (2018)'de bir greyder kepçesi İstanbul'daki üçüncü Havalimanı inşaatı için kesilmiş ağaçları sürüklemektedir. Aydın, bu çalışmada gerçekleştirilen yıkımlara, tahribata ve çevre sistemlerinin ilerlemesi karşısında kırılganlığa dikkat çekmiştir. Bianel sonunda ağaç dalları yok olup çürürken, kepçe yıkıma kaldığı yerden devam edecektir http://bulten.iksv.org/15B_exhibition.pdf (06.06.2022).



Resim 7: Alper Aydın, "D8M", 2017.

Sanayinin gelişimiyle birlikte madenlere büyük bir gereksinim duyulmaktadır. Yeraltından çıkartılan bu madenler insanoğlunun hayatını kolaylaştırma adına büyük bir konfor sağlarken aynı zamanda devasa bir zararı da ortaya koymaktadır. Plansız bir şekilde açılan maden çukurları araziyi parçalamakta ve toprak yapısını bozarak verimsiz hale getirmektedir. Zaman içinde biçim, renk, doku, şekil hatta koku bakımından büyük bir değişime uğrayan toprak yapısı gerçek doğa görüntüsünden uzaklaşarak insan eliyle oluşturulan "Sahte Doğa"lara dönüşmektedir. Araştırmacı Yasin Çakır, Endüstri Devrimi'yle birlikte değişime uğrayan doğayı ele alan resim çalışmaları ele almıştır. Nitekim rant uğruna toprağın kazılması ve maddi arayışa girilmesinin ardından oluşan görünümleri resmettiği "Yok Ettiğiniz Dünya" isimli çalışmasında buna örnek olarak gösterilebilir. Bu "Sahte Doğa"lar yakın gelecekte insanlığın karşılaşacağı, gezintiye çıkacağı panoramalardır.



Resim 8: Yasin Çakır, "Yok Ettiğiniz Dünya", 90 x 110 cm. T.Ü.A.B. 2022.

Bu çalışmalar, Antroposen çağında insanın çevre üzerindeki etkisini görünür kılan sanat pratikleri olarak değerlendirilebilir. Böylece sanat eseri yalnızca estetik bir nesne olmaktan çıkarak çevresel farkındalık oluşturan ve insanın doğayla kurduğu ilişkiyi sorgulayan eleştirel bir alana dönüşmektedir.

SONUÇ

Doğa, kendi sınırları dahilinde sürekli bir devinim gösteren, gelişen, değişen ve canlı-cansız varlıkların tümünü kapsamaktadır. İnsanlık tarihi boyunca doğa sürekli bir gizem uyandırmış ve insana ilham vermiştir. Mağara duvarlarına yapılan ilk resim örnekleri zaman içinde yeni yöntem ve tekniklerle sanat olarak dönüşüme uğramıştır. İnsanlara hayat veren doğanın resimlerini birçok ressam ele almış ve manzara resmine yeni yorumlar getirmiştir. Önceleri insan figürü ardında bir fon görevi gören manzara, 14. yüzyılda Rönesans'la birlikte büyük değişime uğrayarak değer bulmuş ve insanla eşdeğer konuma gelmiştir. Barok dönemde insan ve manzara resimleri artık iç içe kullanılmış hatta bazen salt bazen manzara resimleri yapılmaya başlanmıştır. 19. yüzyıl başlarında romantik akım ile büyük değişeme uğrayan manzara resimlerinde insan doğa birlikteliği azalarak yerine saf doğa görünümlerine bırakmıştır. Bunun sebebi Endüstri Devrimi olarak gösterilebilir. Çünkü mekanik güçler karşısında duyulan çaresizlik insanlığı yalnızlığa, kimsesizliğe itmiş ve insanın yabani doğayla yeniden iletişime geçmeye başladığı görülmüştür. Aynı şekilde bu durum realizm, empresyonizm, fütürizm ve birçok sanat akımında yer bulmuştur.

Endüstri Devrimi'nin yaşanmasıyla birlikte teknolojik, sosyal, tarımsal ve birçok alanda yenilik meydana gelmiştir. Bu yaşanan gelişimlerin ardından kapitalist düzenin doğaya daha da hâkim olmaya başladığı gözlenmiştir. Doğaya sahip olma doğal kaynakların tükenmesine, çevre kirliliğine, doğal yapının bozulmasına neden olmuştur. Bu anlatıların yanında sanat alanında da birçok yenilik yaşanmıştır. Antroposen Çağ'da sanatçılar, aktivistler disiplinlerarası bir süreç izleyerek ilgiyi tahribatın yaşandığı dünyaya çekmişlerdir. Doğanın içine nüfus eden sanayi çevrenin değişimini, yok oluşunu ve de tahribatında etkili olmaya başlamıştır. Çoğu sanatçı 20. yüzyılın başlarından günümüze dek sanayileşme ile artan iklim değişikliklerini, genişleyen ozon tabakasını, eriyen buzulları, maden için açılan çukurları, erozyona uğrayan bitki örtüsünü bir problem olarak görmüşlerdir. Sanatçılar Endüstri Devrimi'ne karşı tepkilerini etrafında şekil alan sanayi ve kent oluşumlarını birçok teknik ve yöntemle eserlerine yansıtmaya çalışmışlardır.

Sonuç olarak bu çalışmada doğanın her çağda dönemin koşullarından etkilenerek değişim gösterdiği saptanmıştır. Çevrenin ve doğal yapının tahrip edilmesinde Endüstri Devrimi'nin büyük bir payı olduğu ortaya konulmuştur. Ayrıca çalışmalarında çevrenin tahribatına vurgu yapan sanatçıların eserleri incelenmiş, yorumlar yapılmış ve görsel verilerle desteklenmiştir.

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LANGUAGE SKILLS AND ANXIETY LEVELS IN CHILDREN WITH AND WITHOUT LANGUAGE DISORDER: A COMPARATIVE AND CORRELATIONAL STUDY

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ABSTRACT

Objective

This study aimed to compare language skills and anxiety levels in children with and without language disorder and to examine the relationship between overall oral language performance and anxiety.

Methods: Seventy children aged 72–121 months participated in the study, including 35 children with language disorder and 35 children without language disorder. Language skills were assessed using the Test of Language Development–Turkish (TODİL), while anxiety levels were assessed using the Spence Children's Anxiety Scale-Parent Form. Language performance was examined across listening, organizing, speaking, grammar, semantics, and overall oral language, whereas anxiety was evaluated using total and subdomain scores. Between-group comparisons were conducted using independent-samples *t* tests and Mann–Whitney *U* tests, as appropriate. Spearman's rank correlation analysis was used to examine associations between overall oral language and total anxiety scores.

Results: Children with language disorder had significantly lower overall oral language scores than children without language disorder ($p<.001$). They also demonstrated significantly poorer performance in listening, organizing, speaking, grammar, and semantics (all $p<.001$). Total anxiety scores were significantly higher in children with language disorder ($p=.027$). Regarding anxiety subdomains, children with language disorder had significantly higher social phobia ($p=.016$) and panic attack/agoraphobia ($p=.033$) scores. No significant group differences were found for separation anxiety, generalized anxiety, obsessive-compulsive symptoms, or fear of physical injury (all $p>.05$). No significant correlations were observed between overall oral language and total anxiety in the language disorder group ($p=.455$), control group ($p=.594$), or total sample ($p=.068$).

Conclusion: Children with language disorder demonstrated poorer language skills and higher overall anxiety, particularly in social phobia and panic/agoraphobia. However, overall oral language performance was not significantly associated with total anxiety. These findings emphasize the importance of considering emotional functioning alongside language abilities in the assessment of children with language disorders.

Keywords: Language disorders, language skills, anxiety

YEŞİL SENTEZ YAKLAŞIMIYLA HAZIRLANAN BARBUNYA KABUĞU–KOBALT FERRİT MANYETİK KOMPOZİTİNİN PONCEAU 4R BOYAR MADDESİNİN GİDERİMİNDE KULLANILMASI

REMOVAL OF PONCEAU 4R DYE FROM AQUEOUS SOLUTIONS USING A GREEN-SYNTHESIZED BEAN POD–COBALT FERRITE MAGNETIC COMPOSITE

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ÖZET
Endüstriyel faaliyetlerden kaynaklanan boyar madde içeren atık sular, çevre ve insan sağlığı açısından önemli bir kirlilik problemidir. Bu çalışmada, tarımsal bir atık olan barbunya kabuğundan yararlanılarak yeşil sentez yaklaşımıyla kobalt ferrit ($CoFe_2O_4$) nanoparçacıkları sentezlenmiş ve barbunya kabuğu ile birleştirilerek manyetik bir biyokompozit adsorban geliştirilmiştir. Çalışmanın amacı, hazırlanan kompozitin azo yapılı bir gıda boyası olan Ponceau 4R'nin sulu çözeltilerden giderimindeki performansını değerlendirmektir.
Sentezlenen $CoFe_2O_4$ nanoparçacıkları ve barbunya kabuğu–$CoFe_2O_4$ kompoziti FTIR, XRD ve FESEM-EDX analizleri ile karakterize edilmiştir. Adsorpsiyon performansının belirlenmesi amacıyla çözelti pH'ı, adsorban miktarı, temas süresi ve başlangıç boyar madde derişiminin etkileri incelenmiştir. Optimum koşullar pH 2, 0,200 g adsorban miktarı, 5 mg/L başlangıç derişimi ve 30 dakika temas süresi olarak belirlenmiş, bu koşullarda %94,46 Ponceau 4R giderimi elde edilmiştir. Ayrıca adsorpsiyonun oldukça hızlı gerçekleştiği ve yalnızca 5 dakikada yaklaşık %90 giderim sağlandığı belirlenmiştir. Yeniden kullanım çalışmalarında adsorbanın birden fazla çevrimde etkinliğini büyük ölçüde koruduğu görülmüştür.
Sonuç olarak, barbunya kabuğu–$CoFe_2O_4$ kompoziti; düşük maliyeti, çevre dostu üretim yöntemi, manyetik olarak kolay ayrılabilmesi ve yüksek adsorpsiyon performansı sayesinde boyar madde içeren atık suların arıtımı için umut vadeden sürdürülebilir bir adsorban olarak değerlendirilmektedir. Ayrıca, barbunya kabuğu esaslı manyetik $CoFe_2O_4$ kompozitinin Ponceau 4R gideriminde kullanılmasına ilişkin literatürde benzer bir çalışmaya rastlanmamış olması, çalışmanın özgün değerini ortaya koymaktadır.
Anahtar kelimeler: Barbunya kabuğu, Kobalt ferrit, Manyetik kompozit, Adsorpsiyon, Ponceau 4R.

ABSTRACT
Dye-containing wastewater generated by industrial activities poses a significant threat to the environment and human health. In this study, cobalt ferrite ($CoFe_2O_4$) nanoparticles were synthesized via a green synthesis approach using common bean (Phaseolus vulgaris) pod waste, and subsequently combined with bean pod powder to fabricate a magnetic biocomposite adsorbent. The aim of this study was to evaluate the adsorption performance of the prepared composite for the removal of Ponceau 4R, an azo food dye, from aqueous solutions.
The synthesized $CoFe_2O_4$ nanoparticles and the bean pod–$CoFe_2O_4$ composite were characterized by Fourier Transform Infrared Spectroscopy (FTIR), X-ray Diffraction (XRD), and Field Emission Scanning Electron Microscopy coupled with Energy Dispersive X-ray Spectroscopy (FESEM-EDX).

The effects of solution pH, adsorbent dosage, contact time, and initial dye concentration on the adsorption performance were systematically investigated. The optimum adsorption conditions were determined as pH 2, an adsorbent dosage of 0.200 g, an initial dye concentration of 5 mg/L, and a contact time of 30 min, under which a maximum removal efficiency of 94.46% was achieved. Furthermore, the adsorption process was remarkably rapid, reaching approximately 90% dye removal within only 5 min. Reusability studies demonstrated that the magnetic composite retained a considerable portion of its adsorption efficiency over multiple adsorption–desorption cycles.

In conclusion, the bean pod–$CoFe_2O_4$ magnetic composite exhibits great potential as a sustainable adsorbent for dye-contaminated wastewater due to its low production cost, environmentally friendly synthesis route, facile magnetic separation, and high adsorption efficiency. Moreover, to the best of our knowledge, no previous study has reported the use of a bean pod-based magnetic $CoFe_2O_4$ composite for the removal of Ponceau 4R, highlighting the novelty of the present work.

Keywords: Bean pod, Cobalt ferrite, Magnetic composite, Adsorption, Ponceau 4R.

GİRİŞ

Su, yaşam için vazgeçilmez en önemli kaynaklardan biridir. Günümüz dünyasında nüfusun artması, teknolojinin gelişmesi, kirliğin artması ve su kaynaklarının azalması nedeniyle, temiz ve güvenli su talebi hızla artmakta, suyun korunması dünya genelinde giderek daha önemli bir sorun haline gelmektedir [1-4]. Dünya genelinde çeşitli zehirli ve zararlı maddeleri içeren atık sular yüksek miktarlarda ve yeterli arıtma işlemlerinden geçirilmeden çevreye salınmaktadır. Bu nedenle atık suların geri kazanımı ve yeniden kullanımı, günümüz koşullarında kritik bir zorunluluk haline gelmiştir [5].

Çevre kirliliğine neden olan en önemli faktörler arasında büyük miktarlarda üretilen ve birçok endüstrilerde yaygın olarak kullanılan boyar maddeler yer almaktadır [6,7]. Boyar maddeler ciddi su kirliliğine sebep olmakta, su kalitesinin ciddi şekilde bozulmasına yol açmakta, çevreyi ve insan sağlığını tehdit etmektedir [8]. Bu nedenle boyar maddeleri içeren atık suların su kaynakları ile karıştırılmasına izin verilmemesi, çevreye bırakılmadan önce arıtılması halk sağlığı ve çevre açısından hayati bir gerekliliktir [9].

Sulu çözeltilerden boyar madde gideriminde en çok kullanılan yöntemlerden biri adsorpsiyon yöntemidir. İşlem kolaylığı, yüksek etkinlik göstermesi, düşük sıcaklıkta çalışılması, maliyet etkin olması, kirleticilerin aynı anda uzaklaştırılabilmesi gibi avantajlara sahip bir yöntemdir [8, 10]. Ancak, kullanılan doğal adsorbanların sınırlı performansı, sentetik adsorbanların yüksek maliyeti ve çevre dostu olmaması gibi problemler bulunmaktadır. Bu nedenle, doğal ve sentetik adsorbanların avantajlarını birleştiren ekonomik, etkinliği yüksek, geri dönüştürülebilir ve çevre dostu yeni adsorbanların geliştirilmesi önem taşımaktadır [11].

Yirmi birinci yüzyılda nanoteknoloji, atık su arıtımında etkili, yüksek teknolojiye sahip malzemelerin geliştirilmesinde önemli bir rol oynamaktadır. Nanomalzemeler zararlı organik ve inorganik kirleticileri sulardan gidermek için son derece etkili bir malzeme olarak kullanılan yeni nesil adsorbanlardır [12]. Şimdiye kadar geliştirilen yeni nesil adsorban malzemeler arasında yer alan manyetik nano adsorbanlar geniş yüzey alanına, ayarlanabilir morfolojiye, adsorpsiyon sonrası kolay ayrılabilirliğe ve yüksek verimliliğe sahip umut verici ve üstün adsorbanlar olarak görülmektedir [13-15]. Bunlar arasında kobalt ferrit ($CoFe_2O_4$) fiziksel, kimyasal, manyetik, elektriksel ve optik özellikleri nedeniyle kapsamlı bir şekilde araştırılan önemli bir manyetik malzemedir. Çevresel kirlilik giderimi, enerji depolama, kataliz, sensörler, transistörler, güneş hücreleri, tıp ve biyomedikal gibi çeşitli uygulamalarda kullanılmaktadır [16-20]. Manyetik nano adsorbanlar dış manyetik alan uygulanarak kolaylıkla çözeltilerden ayrılabilirler, tekrar kullanılabilirler, biyouyumlulukları nedeniyle çevre dostudurlar, laboratuvar ölçeğinde çeşitli hedef kirleticileri uzaklaştırmak için hazırlanabilir ve modifiye edilebilirler [21]. Ancak çoğu ticari olarak temin edilebilen manyetik nanoparçacıklar, pahalı oldukları için büyük ölçekli işlemlerde kullanılamamaktadır. Ayrıca manyetik nanoparçacıkların yüksek yüzey enerjisi, proses sırasında aglomerasyona neden olabilir. Bu da etkinliğinin azalmasına yol açar. Bu sınırlamalar manyetik nanoparçacıklarla birlikte destek materyali kullanma ihtiyacını ortaya koymuştur [22, 23].

Ayrıca son zamanlarda araştırmacıların odak noktası sentetik adsorbanların yüksek üretim maliyetleri nedeniyle, biyomalzemeler de dahil olmak üzere sürdürülebilir malzemelere kaymıştır [12]. Algler, mantarlar, tarımsal atıklar ve mikrobiyal biyokütle gibi biyomateryallerin adsorban olarak kullanımı umut verici ve çevre dostu bir çözüm olarak öne çıkmaktadır.

Son yıllarda, tarımsal yan ürünlere veya atıklara dayalı adsorbanlar, düşük maliyetleri, bol bulunmaları, işlem kolaylığı, yüksek etkinlik, biyouyumlulukları ve yenilenebilirlikleri gibi nedenlerle gittikçe artan bir ilgi görmektedir [24]. Ancak kullanımlarını sınırlayan ana problem, adsorbanın sudan ayrılmasının zor olmasıdır. Bu durum, araştırmacıları adsorbanlara manyetik özellik kazandırmanın olası bir çözümünü bulmaya yöneltmiştir [12].

Özetle manyetik parçacıkların yüksek maliyeti ve aglomerasyonu; doğal adsorbanların düşük adsorpsiyon verimliliği ve sulu ortamdan zor uzaklaştırılması gibi dezavantajlarının üstesinden gelmek, sentetik ve doğal adsorbanların avantajlarını birleştirmek için manyetik nanoparçacıkların biyomalzemeler ile birleştirildiği manyetik kompozit adsorbanlar dikkat çekmektedir [12, 22, 23, 25]. Düşük maliyetli adsorbanların manyetik malzemelerle birleştirildiği kompozitlerin en büyük avantajı, çok kısa bir süre içinde, büyük miktarda atık suyu arıtabilmesidir. Manyetik olarak modifiye edilmiş biyokompozit, bir dış manyetik alanla sudan kolaylıkla ayrılabilmekte ve tekrar kullanılabilmektedir. Bu da geleneksel ayırma teknikleri (filtrasyon, santrifüjleme, çöktürme) ile karşılaştırıldığında önemli çevresel ve ekonomik avantajlar sağlar [26].

MATERYAL VE METOT

Bu çalışmada, daha önce çalışma grubumuz tarafından yeşil sentez yaklaşımıyla hazırlanan ve yapısı karakterize edilen [27], barbunya kabuğu-nano $CoFe_2O_4$ manyetik kompoziti Ponceau 4R gideriminde adsorban olarak kullanılmıştır. Adsorpsiyona pH'ın, sürenin, başlangıç boyar madde derişiminin ve adsorban miktarının etkisi incelenerek, parametreler optimize edilmiştir. Ayrıca adsorbanın tekrar kullanılabilirliği araştırılmıştır. Adsorpsiyon deneyleri bilinen pH, süre, adsorban miktarı ve başlangıç boyar madde derişiminde, 50 mL'lik cam beherlerin içerisine 25 mL Ponceau 4R çözeltilerinin konularak karıştırılması ile gerçekleştirilmiştir. Boyar madde çözeltilerinin pH değerleri 0,01 M HCl ve 0,01 M NaOH çözeltileriyle ayarlanmıştır. Adsorpsiyon süresinin tamamlanmasından sonra adsorban mıknatıs yardımıyla çözeltiden ayrılmıştır. Çözelti 0,22 μm şırınga ucu filtreden süzülerek, λ_{max}=506 nm'deki absorpsiyon değerleri UV Spektrofotometresi ile ölçülerek çözeltide kalan Ponceau 4R derişimi belirlenmiştir. Ponceau 4R'nin sulu çözeltisinin maksimum absorpsiyon yaptığı dalga boyu (λ_{max}) ultraviyole/görünür bölge spektrumu alınarak belirlenmiştir. Spektrumlar referans suya karşı alınmıştır. Boyar maddenin % Giderimi spektrofotometrik olarak aşağıdaki eşitlik kullanılarak belirlenmiştir.

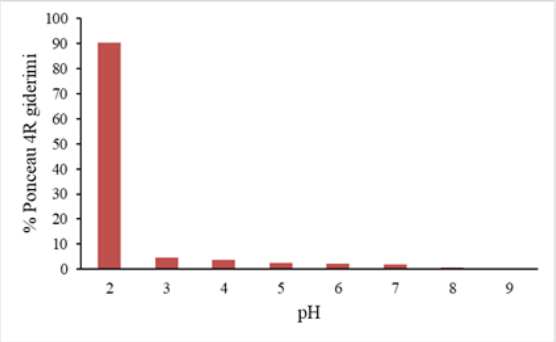
$$\text{Giderim (\%)} = [(C_0 - C) / C_0] \times 100$$

Burada C_0 başlangıç Ponceau 4R derişimini (mg/L), C ise adsorpsiyon işlemi sonunda çözeltide kalan Ponceau 4R derişimini (mg/L) ifade etmektedir.

Adsorbanın tekrar kullanılabilirliğinin belirlenmesi amacıyla optimum koşullarda adsorpsiyon deneyleri gerçekleştirilmiştir. Her çevrim sonunda adsorban mıknatıs yardımıyla ayrılmış, renk vermeyene kadar saf suyla yıkanmış, 50 °C'de kurutulmuş ve aynı koşullarda yeniden kullanılmıştır. Bu işlem toplam 10 çevrim boyunca tekrarlanmıştır.

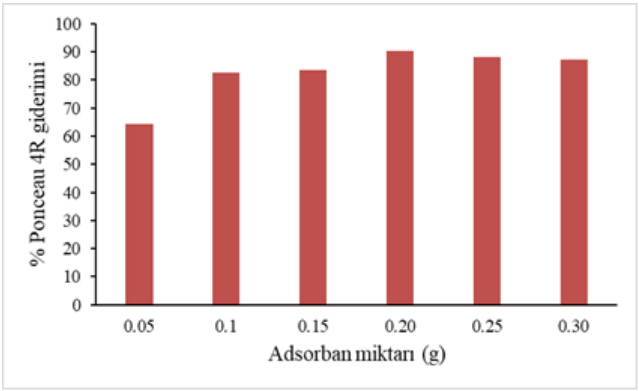
BULGULAR VE TARTIŞMA

pH boyar maddelerin adsorpsiyonunda temel parametrelerden biridir. Adsorban malzemelerin yüzey yükleri ve bileşiklerin iyonlaşma derecesi çözeltinin pH değerinden hassas bir şekilde etkilenir [28]. Barbunya kabuğu-nano $CoFe_2O_4$ kompoziti kullanılarak, anyonik bir boyar madde olan Ponceau 4R'nin sulu ortamdan giderilmesinde çözelti pH'sının etkisini incelemek için yapılan çalışmalarda, pH'ı 2 ile 9 arasında olan boyar madde çözeltileri kullanılmıştır. 5 mg/L derişimindeki boyar madde çözeltilerinin pH'sı istenen değerlere ayarlandıktan sonra, 0,200 g adsorban ile 60 dakika karıştırma süresi sonunda alınan örneklerin absorbans değerleri ölçülerek, boyar maddenin % giderimi hesaplanmıştır. Şekil 1'de görüldüğü gibi en yüksek boyar madde gideriminin pH 2'de %90,24 olduğu, diğer pH değerlerinde giderimin çok düşük olduğu belirlenmiştir. Daha sonraki aşamalarda pH 2'de çalışılmıştır. Literatürdeki çalışmalarda da genellikle, düşük pH'da spinel ferritlerin yüzeyinin pozitif yüklü olduğu, negatif yüklü anyonik boyar madde anyonu ile arasındaki güçlü elektrostatik etkileşim nedeniyle giderimin yüksek olduğu, pH arttıkça elektrostatik itme nedeniyle adsorpsiyonun azaldığı rapor edilmektedir [13, 28-29].



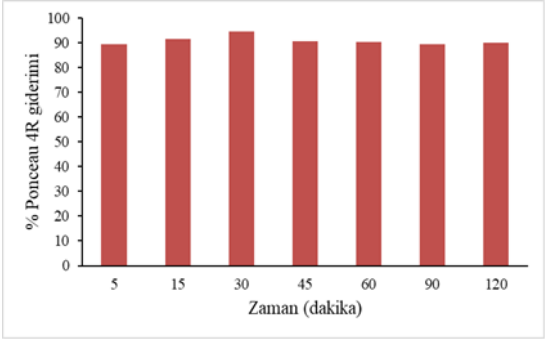
Şekil 1. Ponceau 4R giderimine çözelti pH'sının etkisi

Adsorban miktarının etkisini incelemek için altı farklı adsorban miktarı çalışılmıştır. Şekil 2'de görüldüğü gibi pH değeri 2'ye ayarlanmış, 5 mg/L başlangıç boyar madde derişiminde başlangıçta adsorban miktarı arttıkça % giderimin arttığı, 0,200 g adsorban miktarından sonra giderimin hemen hemen sabit kaldığı görülmektedir. Bundan sonraki çalışmalarda 0,200 g adsorban kullanılmıştır. Adsorban miktarı adsorpsiyon sürecini etkileyen önemli bir parametredir. Sabit boyar madde derişimlerinde, adsorban miktarı artıkça adsorpsiyon için daha çok aktif yüzey alanı ve aktif adsorpsiyon bölgeleri mevcuttur [29]. Bu nedenle adsorban miktarındaki bir artış, boyar madde giderimini artırmaktadır [30]. Literatürde; adsorban miktarı arttıkça etkinliğin arttığı rapor edilmektedir. Birkaç çalışmada, verimlilikteki bu artışın bir doygunluk durumuna ulaşılana kadar sürdüğü ve ardından bazen hafifçe ama sürekli olarak azaldığı bildirmektedir. Bu, belirli bir adsorban dozundan sonra maksimum adsorpsiyona ulaşılması ile açıklanmaktadır [29].



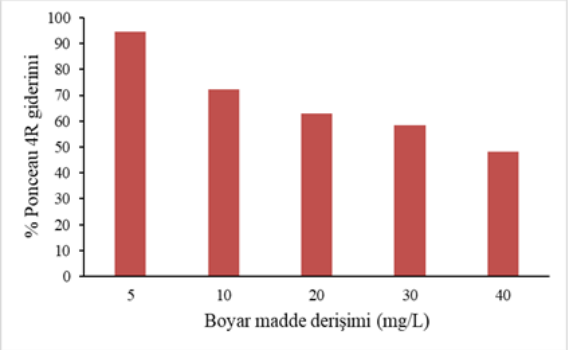
Şekil 2. Ponceau 4R giderimine adsorban miktarının etkisi

Temas süresinin etkisini incelemek için yapılan çalışmada, pH'ı 2,0'a ayarlanmış 25 mL, 5 mg/L derişimindeki boyar madde çözeltisi ve 0,200 g adsorban kullanılmıştır. Şekil 3'te görüldüğü gibi Ponceau 4R gideriminin çok hızlı olduğu, 5 dakikada yaklaşık %90 giderim elde edildiği, 30 dakikaya kadar hafifçe artarak, %94,46 Ponceau 4R giderimi elde edildiği daha sonra hafifçe yaklaşık %90'a azaldığı gözlenmiştir. Optimum süre 30 dakika olarak belirlenmiştir.



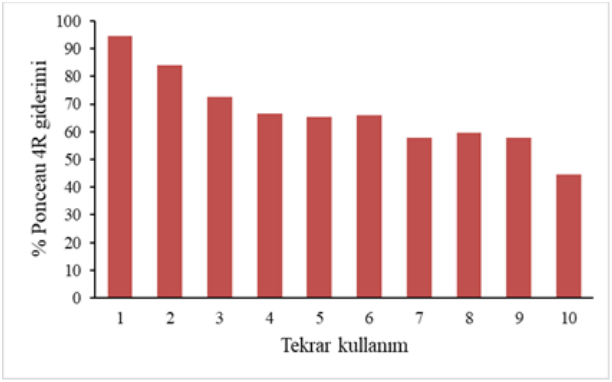
Şekil 3. Ponceau 4R giderimine temas süresinin etkisi

Başlangıç Ponceau 4R derişiminin etkisini incelemek için yapılan çalışmalarda pH'ı 2,0'a ayarlanmış 25 mL, 5, 10, 20, 30 ve 40 mg/L derişimlerindeki boyar madde çözeltileri ve 0,200 g adsorban kullanılarak 30 dakika temas süresinde boyar madde derişiminin etkisi incelenmiştir. Şekil 4'te görüldüğü gibi, 5 mg/L boyar madde derişiminde %94,46 giderim elde edilmiş olup, boyar madde derişimi arttıkça giderim azalmıştır. Düşük derişimlerde adsorban yüzeyindeki aktif bölgelerin boyar madde moleküllerine oranının yüksek olması yüksek giderim sağlarken, başlangıç derişiminin artmasıyla sabit sayıdaki adsorpsiyon bölgelerinin doygunluğa yaklaşması giderim yüzdesinin azalmasına neden olmuştur.



Şekil 4. Ponceau 4R giderimine başlangıç boyar madde derişiminin etkisi

Kompozitin tekrar kullanılabilirlik deneylerinde çevrim sayısının artmasıyla Ponceau 4R giderim performansında kademeli bir azalma gözlenmiştir. İkinci ve üçüncü kullanımlarda giderim sırasıyla %83,93 ve %72,62 olarak belirlenirken, 4.–6. çevrimlerde yaklaşık %66 giderim elde edilmiştir. Performanstaki azalmanın, yıkama sonrasında bazı adsorplanmış boyar madde türlerinin aktif bölgelerde kalması ve ardışık çevrimlerde kullanılabilir adsorpsiyon bölgelerinin azalmasıyla ilişkili olabileceği düşünülmektedir. Bununla birlikte kompozitin birden fazla çevrimde giderim etkinliğini sürdürmesi ve manyetik özelliği sayesinde çözeltiden kolaylıkla ayrılabilmesi, tekrar kullanım açısından önemli bir avantaj sağlamaktadır.



Şekil 5. Barbunya kabuğu-nano $CoFe_2O_4$ kompozitinin tekrar kullanım performansı

SONUÇ

Bu çalışmada barbunya kabuğu-nano $CoFe_2O_4$ kompozitinin Ponceau 4R'nin sulu ortamdan gideriminde etkili bir manyetik adsorban olduğu belirlenmiştir. Optimum deneysel koşullar pH 2,0, 25 mL çözelti hacmi, 5 mg/L başlangıç Ponceau 4R derişimi, 0,200 g adsorban miktarı ve 30 dakika temas süresi olarak belirlenmiş ve bu koşullarda %94,46 giderim elde edilmiştir. Kompozitin yalnızca 5 dakikada yaklaşık %90 giderim sağlaması hızlı adsorpsiyon davranışını ortaya koymuştur. Ayrıca adsorbanın manyetik özelliği sayesinde çözeltiden kolaylıkla ayrılması ve ardışık çevrimlerde yeniden kullanılabilmesi önemli avantajlar sağlamaktadır. Elde edilen sonuçlar, tarımsal atık temelli barbunya kabuğu ile nano $CoFe_2O_4$'ün birleştirilmesiyle hazırlanan kompozitin boyar madde içeren sulu ortamların arıtımında kullanılabilecek düşük maliyetli ve yeniden kullanılabilir bir adsorban olma potansiyeline sahip olduğunu göstermektedir.

Teşekkür
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THE SECOND-TO-FOURTH DIGIT RATIO (2D:4D) AS A PRENATAL DEVELOPMENTAL BIOMARKER: A BIBLIOMETRIC AND KNOWLEDGE-MAPPING ANALYSIS OF THE GLOBAL LITERATURE

DOĞUM ÖNCESİ GELİŞİMSEL BİR BİYOBELİRTEÇ OLARAK İKİNCİ-DÖRDÜNCÜ PARMAK ORANI (2D:4D): KÜRESEL LİTERATÜRÜN BİBLİYOMETRİK VE BİLGİ HARİTALAMA ANALİZİ

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ABSTRACT
The second-to-fourth digit ratio (2D:4D) is a sexually dimorphic, non-invasive proxy for prenatal androgen exposure. Since Manning et al. (1998) linked relative digit length to testosterone and estrogen, 2D:4D has been applied across reproductive biology, psychology, sports science, and psychiatry—yet no comprehensive bibliometric synthesis exists. We mapped the global 2D:4D literature (1998–2025) using Web of Science Core Collection records analyzed in R (Bibliometrix). Of 1,674 original articles by 5,119 authors in 644 sources, annual output plateaued at 90–112 articles/year during 2015–2021 (mean citations = 27.5; 31.4% international co-authorship). *Personality and Individual Differences* (n = 118), *Early Human Development* (n = 103), and *American Journal of Human Biology* (n = 89) were most productive; *Archives of Sexual Behavior* showed highest local impact (h = 28). The USA, UK, Germany, China, and Türkiye led production; J.T. Manning authored 101 articles. Thematic mapping revealed a stable testosterone–digit-ratio core surrounded by clusters on sexual dimorphism, sexual orientation, prenatal androgen exposure, and lateralisation. Trend topics migrated from basic morphology toward clinical and neurodevelopmental applications. The field is mature and geographically broad, anchored to the prenatal-androgen hypothesis while diversifying methodologically. We also identify homonym-driven contamination by unrelated physics literature that future searches must control for.
Keywords: 2D:4D, bibliometric analysis, digit ratio, prenatal testosterone, science mapping

ÖZET
İkinci-dördüncü parmak oranı (2D:4D), prenatal androjen maruziyetinin cinsiyete göre farklılık gösteren, invaziv olmayan bir göstergesidir. Manning ve ark. (1998) göreceli parmak uzunluğunu testosteron ve östrojen ile ilişkilendirdiğinden bu yana, 2D:4D üreme biyolojisi, psikoloji, spor bilimleri ve psikiyatri gibi alanlarda uygulanmış; ancak bugüne kadar kapsamlı bir bibliyometrik sentezi yapılmamıştır. Bu çalışmada, Web of Science Core Collection kayıtları kullanılarak 1998–2025 dönemine ait küresel 2D:4D literatürü R (Bibliometrix) yazılımı ile analiz edilmiştir. Toplam 644 kaynakta yayımlanan, 5.119 yazar tarafından kaleme alınmış 1.674 özgün makale incelenmiştir. Yıllık yayın sayısı 2015–2021 döneminde yılda 90–112 makale düzeyinde plato göstermiştir (ortalama atıf = 27,5; uluslararası ortak yazarlık oranı = %31,4). En üretken dergiler *Personality and Individual Differences* (n = 118), *Early Human Development* (n = 103) ve *American Journal of Human Biology* (n = 89) olurken; *Archives of Sexual Behavior* en yüksek yerel etkiye (h = 28) sahip dergi olarak belirlenmiştir. Amerika Birleşik Devletleri, Birleşik Krallık, Almanya, Çin ve Türkiye en fazla yayın üreten ülkeler olup; J.T. Manning 101 makale ile en üretken yazar olmuştur. Tematik haritalama, testosteron–parmak oranı ekseninde istikrarlı bir çekirdeğin; cinsel dimorfizm, cinsel yönelim, prenatal androjen maruziyeti ve lateralizasyon kümeleriyle çevrelendiğini ortaya koymuştur. Eğilim konuları temel morfolojiden klinik ve nörogelişimsel uygulamalara doğru kaymıştır.

Alan, prenatal androjen hipotezine dayanan, metodolojik açıdan çeşitlenen, olgunlaşmış ve coğrafi olarak geniş bir araştırma alanıdır. Ayrıca, gelecekteki literatür taramalarında kontrol edilmesi gereken, ilgisiz fizik literatüründen kaynaklanan eş adlı (homonim) kayıt kirliliği de belirlenmiştir.
Anahtar Kelimeler: 2D:4D, bibliyometrik analiz, parmak oranı, prenatal testosteron, bilim haritalama.

INTRODUCTION

The ratio between the length of the second (index) and fourth (ring) fingers, universally abbreviated as 2D:4D, is a sexually dimorphic trait: on average it is lower in men than in women. Interest in this seemingly trivial anatomical proportion was transformed by the seminal report of Manning and colleagues, who proposed that a low 2D:4D reflects relatively high prenatal testosterone and low prenatal oestrogen exposure, and demonstrated correlations with sperm number and circulating sex-steroid concentrations (Manning et al., 1998). Because the ratio is fixed early in gestation and remains comparatively stable thereafter, it has since been promoted as a convenient, non-invasive and retrospective proxy of the intrauterine hormonal milieu (Manning & Fink, 2008).

Mechanistic support for this interpretation has accumulated across experimental and clinical models. Developmental work in the mouse established that the relative growth of the digits is under the joint control of androgen and oestrogen receptor signalling during a narrow prenatal window (Zheng & Cohn, 2011), and studies of individuals with congenital adrenal hyperplasia—a condition of elevated fetal androgens—have repeatedly reported masculinised (lower) digit ratios (Brown et al., 2002). On this foundation, 2D:4D has been deployed as an explanatory or predictive variable across an unusually wide range of disciplines, from reproductive and developmental biology to psychology, sports science, behavioural economics, psychiatry and forensic anthropology.

This breadth is also the source of persistent controversy. Effect sizes are frequently small, replication is inconsistent, and the validity of 2D:4D as a faithful index of prenatal androgen action has been repeatedly questioned (Voracek & Dressler, 2006). Literature has consequently grown not only in volume but in internal heterogeneity, encompassing confirmatory studies, null findings, meta-analyses and methodological critiques. Such a configuration—large, interdisciplinary, contested and rapidly expanding—is precisely the setting in which bibliometric and science-mapping methods add value, by rendering the structure and evolution of a field visible in a reproducible, quantitative manner (Aria & Cuccurullo, 2017).

Bibliometric analysis uses the measurable properties of scientific publications—authorship, sources, citations, keywords and their co-occurrence—to describe the productivity, impact, collaboration patterns and conceptual organisation of a research domain (Donthu et al., 2021). Although bibliometric mapping has been applied to many biomedical and psychological topics, and although several narrative and systematic reviews of 2D:4D exist, no comprehensive bibliometric synthesis of the global digit-ratio literature has been published. The present study addresses this gap.

Accordingly, the objectives of this study were: to describe the temporal evolution of scientific production on 2D:4D from its foundational year 1998 to 2025; to identify the most productive and most influential sources, countries, institutions, authors and documents; to map the intellectual and conceptual structure of the field through keyword co-occurrence and thematic mapping; and to characterise the thematic evolution and emerging fronts of the field through trend-topic detection.

MATERIALS AND METHODS

Study design and data source

A descriptive, retrospective bibliometric design was adopted, following the three-stage framework of data collection, screening and analysis that is standard in the field (Aria & Cuccurullo, 2017; Donthu et al., 2021). The Web of Science Core Collection (WoSCC; Clarivate Analytics) was selected as the single data source because of its curated coverage of high-impact journals, its rigorous indexing of cited references, and its interoperability with dedicated bibliometric software.

Search strategy

A comprehensive topic (TS) query was constructed to capture the full terminological variability of the digit-ratio construct. The final search string was:

TS=("2D:4D" OR "2D:4D ratio" OR "2D/4D" OR "2D:4D digit ratio" OR "digit ratio" OR "digit ratios" OR "digit length ratio" OR "second to fourth digit ratio" OR "second-to-fourth digit ratio" OR "2nd to

4th digit ratio" OR "second to fourth finger ratio" OR "finger length ratio" OR "finger ratio" OR "index to ring finger ratio" OR "index-to-ring finger ratio" OR "ratio of index to ring finger")
The search was executed on the full WoSCC timespan available for the topic. Retrieval was then refined by document type and language (see below). The publication-year span of the resulting corpus was 1998–2026; because 2026 was represented by only four early-access records at the time of extraction, the substantive analysis is framed as covering 1998–2025.

Inclusion and exclusion criteria
To ensure a homogeneous corpus of primary research, the WoS document-type filter was applied to retain original articles and to exclude review articles; only English-language records were kept. Records classified purely as editorial material, letters, meeting abstracts or corrections were not included. The final dataset comprised 1,674 documents. Consistent with the descriptive aim of a bibliometric mapping, no methodological quality appraisal of individual studies was undertaken.

Data analysis and science mapping
The full records, including cited references, were exported and analysed in the R statistical environment using the Bibliometrix package and its web interface, Biblioshiny (Aria & Cuccurullo, 2017). Three analytical layers were produced. First, *performance analysis* quantified annual scientific production, citation impact, and the productivity and local impact (h-, g- and m-indices) of sources, authors, institutions and countries; Bradford's law of source scattering and Lotka's law of author productivity were fitted. Second, *science mapping* examined the conceptual structure of the field through keyword co-occurrence networks and through a thematic (strategic) map, in which clusters of co-occurring terms are positioned in a two-dimensional space defined by centrality (relevance) and density (development) (Cobo et al., 2011). Third, *thematic-evolution analysis* used trend-topic detection to locate the median year of use of high-frequency terms and thereby trace the migration of research fronts over time. Figures were generated in Biblioshiny and in Python (Matplotlib) from the exported bibliometric tables.

RESULTS

Main information and annual scientific production
The final corpus comprised 1,674 original articles published between 1998 and 2025 across 644 sources and authored by 5,119 researchers. The documents contained 41,928 cited references, 3,116 Keywords Plus and 3,045 author keywords. The mean number of citations per document was 27.5 and the mean document age 10.6 years, indicating a mature and well-cited field. Collaboration was substantial: the corpus averaged 4.49 co-authors per document, only 115 documents were single-authored, and 31.4% of articles involved international co-authorship (Table 1).

Table 1. Main bibliometric information of the 2D:4D literature (Web of Science Core Collection, 1998–2025).

Indicator	Value
Timespan	1998–2025
Sources (journals, books, etc.)	644
Documents (original articles)	1,674
Annual growth rate	2.51%
Average document age (years)	10.6
Average citations per document	27.47
Cited references	41,928
Keywords Plus (ID)	3,116
Author keywords (DE)	3,045
Total authors	5,119
Single-authored documents	115
Co-authors per document	4.49
International co-authorship	31.42%

Annual production grew from 2 articles in 1998 to a sustained plateau of approximately 90 to 112 articles per year across 2015–2021, peaking at 112 articles in 2018 (Fig. 1). The overall annual growth rate was 2.51%. Citation impact per article, expressed as mean citations per article per year, was dominated by the highly cited foundational cohort: the two 1998 articles accumulated a mean of 20.0 citations per year, after which the metric settled to the 1.3–2.9 range characteristic of a steadily productive mature field. The apparent decline in raw article counts after 2021 is at least partly an artefact of database indexing lag for the most recent years rather than a genuine contraction of the field.

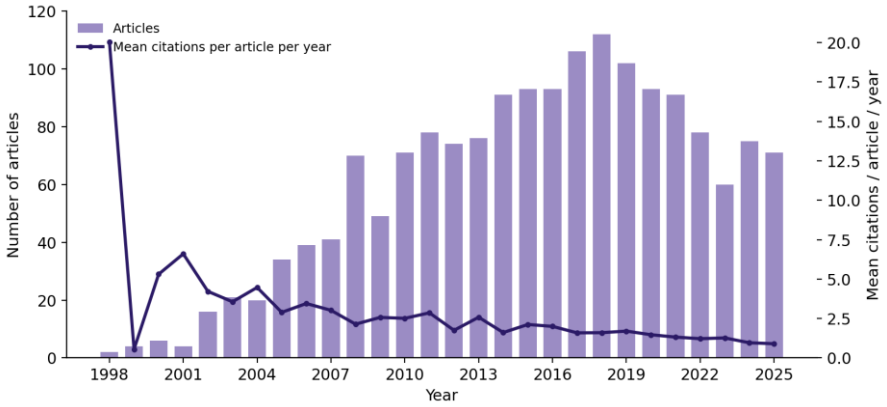


Fig. 1 Annual scientific production (bars, left axis) and mean citations per article per year (line, right axis) for 2D:4D research, 1998–2025.

Most relevant and most influential sources

Publication was concentrated in a small set of specialised journals, consistent with Bradford's law of source scattering: the first Bradford zone comprised only seven journals yet accounted for a disproportionate share of output. The three most productive sources were *Personality and Individual Differences* (118 articles), *Early Human Development* (103) and the *American Journal of Human Biology* (89), followed by *Archives of Sexual Behavior* (59) and *PLOS ONE* (52) (Fig. 2).

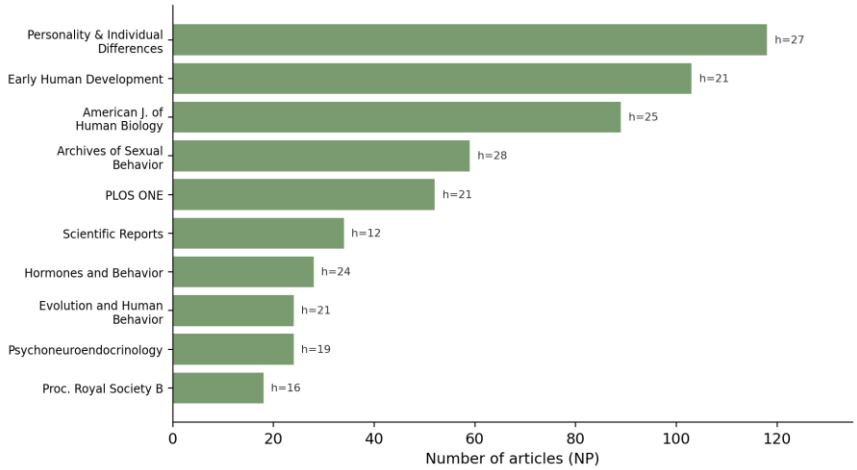


Fig. 2 The ten most productive sources by number of articles (NP); the local h-index of each source is annotated.

Productivity and impact were only partially aligned. When ranked by local h-index, *Archives of Sexual Behavior* emerged as the most influential source (h = 28; 2,581 local citations), narrowly ahead of *Personality and Individual Differences* (h = 27) and the *American Journal of Human Biology* (h = 25). *Early Human Development*, although second in raw output, showed the single highest local citation total (2,969) and a high g-index (52), underscoring its central role in the developmental and clinical strands of the field (Table 2).

Table 2. Ten most productive and locally influential sources in the 2D:4D literature.

Source	NP	h	g	TC
Personality and Individual Differences	118	27	43	2,502
Early Human Development	103	21	52	2,969
American Journal of Human Biology	89	25	50	2,678
Archives of Sexual Behavior	59	28	50	2,581
PLOS ONE	52	21	33	1,264
Scientific Reports	34	12	19	430
Hormones and Behavior	28	24	28	2,317
Evolution and Human Behavior	24	21	24	2,640
Psychoneuroendocrinology	24	19	24	1,122
Proceedings of the Royal Society B	18	16	18	1,452

Countries and international collaboration

Research on 2D:4D was globally distributed, with 83 contributing countries. On the basis of total author appearances, the USA (786), the United Kingdom (556), Germany (298), China (288) and Türkiye (256) were the most productive nations, followed by Poland, Canada, Australia, Spain and Italy. Notably, Türkiye ranked fifth worldwide, reflecting a substantial and sustained national contribution to digit-ratio research.

Citation impact tracked but did not exactly mirror productivity. The United Kingdom recorded the highest total citations (12,810; 59.9 per article), ahead of the USA (10,191; 38.2 per article), Germany, Canada and Austria, indicating a particularly high per-article influence of the British output—consistent with the foundational role of UK-based investigators in the field.

Collaboration patterns, assessed from corresponding-author country and the ratio of single- to multiple-country publications (SCP/MCP), were markedly heterogeneous (Fig. 3). Several European countries and Australia showed high international-collaboration rates (Austria 46.3%, the Netherlands 46.3%, Poland 46.1%, Germany 43.5%, Australia 52.5%), whereas some highly productive countries relied predominantly on domestic collaboration (Türkiye 3.7% MCP; Japan 8.1% MCP). This contrast identifies a clear opportunity for internationalisation of nationally concentrated research programmes.

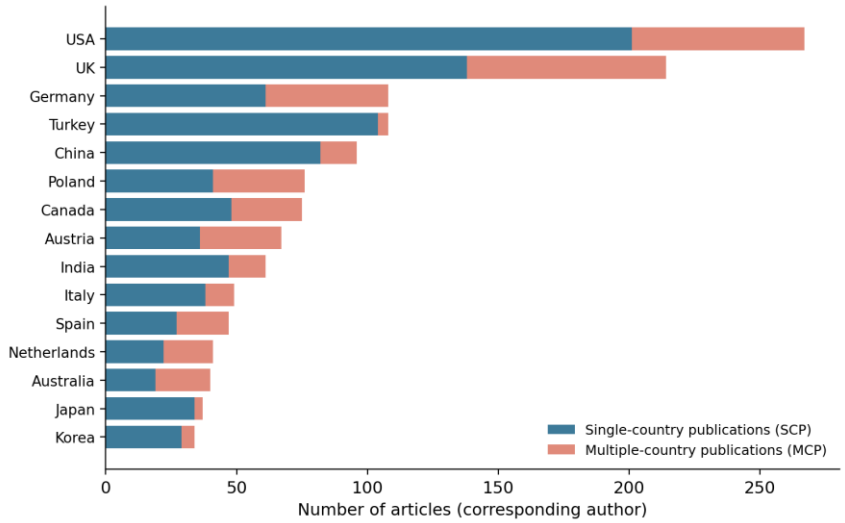


Fig. 3 Corresponding-author production of the fifteen leading countries, partitioned into single-country (SCP) and multiple-country (MCP) publications.

Author productivity

Author productivity followed a strongly skewed Lotka distribution: 80.7% of authors contributed a single article, and only a small elite published prolifically. J.T. Manning—the originator of the modern digit-ratio hypothesis—was by a wide margin the most prolific author, with 101 articles, more than twice the output of the next most productive researchers, B. Fink (48) and M. Voracek (47).

A distinct German psychiatric-genetics group (J. Kornhuber and B. Lenz, 23 articles each) and a Polish plastic-surgery/anthropology group (B. Antoszewski and A. Kasielska-Trojan, 20 each) also emerged as major contributors, illustrating the coalescence of the field around several stable, geographically defined research programmes (Table 3).

Table 3. Ten most productive authors in the 2D:4D literature.

Author	Articles	Fractionalised articles
Manning J.T.	101	30.08
Fink B.	48	14.02
Voracek M.	47	22.86
Kornhuber J.	23	3.76
Lenz B.	23	3.76
Neave N.	22	5.71
Antoszewski B.	20	4.95
Kasielska-Trojan A.	20	4.85
Sitek A.	18	3.46
Breedlove S.M.	15	4.14

Most influential documents

The most globally cited document was the foundational article by Manning et al. (1998, Human Reproduction), which established the association of 2D:4D with sperm number and sex-steroid concentrations and has attracted 1,155 citations. It was followed by Lutchmaya et al. (2004, Early Human Development; 740 citations), which linked the ratio to fetal testosterone and oestradiol measured in amniotic fluid, and by two large methodological/quantitative contributions—Zheng and Cohn (2011, PNAS; 557 citations), which provided the experimental developmental mechanism, and Hönekopp and Watson (2010, American Journal of Human Biology; 420 citations), a meta-analysis of sex differences in the ratio (Table 4). The prominence of these documents confirms that the field remains intellectually anchored to the original prenatal-androgen hypothesis and its mechanistic validation.

Table 4. Ten most globally cited documents in the 2D:4D literature (TC = total citations).

Document (first author, year, source)	TC	TC/year
Manning JT, 1998, Hum Reprod	1,155	39.8
Lutchmaya S, 2004, Early Hum Dev	740	32.2
Zheng ZG, 2011, PNAS	557	34.8
Hönekopp J, 2010, Am J Hum Biol	420	24.7
Brown WM, 2002, Horm Behav	388	15.5
Manning JT, 2000, Evol Hum Behav	338	12.5
Malas MA, 2006, Early Hum Dev	333	15.9
Manning JT, 2001, Dev Med Child Neurol	326	12.5
Manning JT, 2001, Evol Hum Behav	314	12.1
Apicella CL, 2008, Evol Hum Behav	295	15.5

Conceptual structure: keywords and thematic map

After the ratio-name variants themselves, the most frequent substantive terms were *testosterone* (756 occurrences), *sex differences* (in its combined spellings, ~290), *men* (190), *fetal testosterone* (173), *sexual dimorphism* (156), *women* (151), *behavior* (151), *aggression* (141) and *sexual orientation* (99). This lexical profile confirms that the endocrine construct (prenatal/fetal testosterone) and the phenomenon of sex differences form the semantic backbone of the field (Fig. 4).

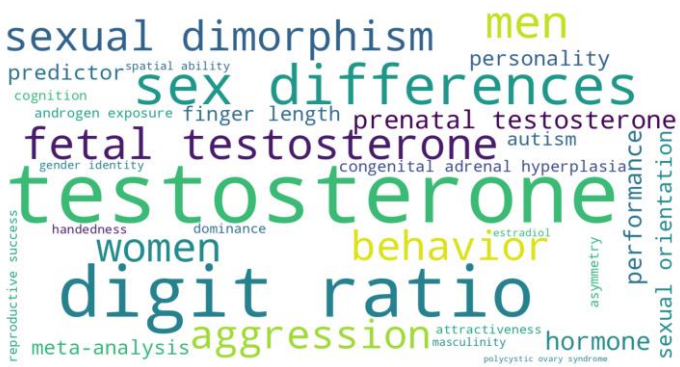


Fig. 4 Word cloud of the most frequent substantive terms in the 2D:4D corpus (ratio-name spelling variants collapsed).

Thematic (strategic) mapping resolved the corpus into a coherent structure organised around a single dominant, highly central and well-developed core cluster labelled *testosterone / digit ratio*, which functions as the transversal, basic theme of the entire field (Fig. 5). Surrounding this core were four specialised clusters. The first was *a sex-differences / fetal-testosterone* cluster oriented toward behaviour, aggression and personality. The second was *a sexual-dimorphism / reproductive-success* cluster linking the ratio to dominance, attractiveness, fluctuating asymmetry and masculinity. The third was *a finger-length-ratios / sexual-orientation* cluster integrating hormones, congenital adrenal hyperplasia and gender-related outcomes. The fourth comprised smaller, more peripheral clusters addressing *prenatal androgen exposure / PCOS and asymmetry / cerebral lateralisation*. The position of these clusters indicates a field with a strong, stable conceptual centre and several actively developing but less central specialised fronts.

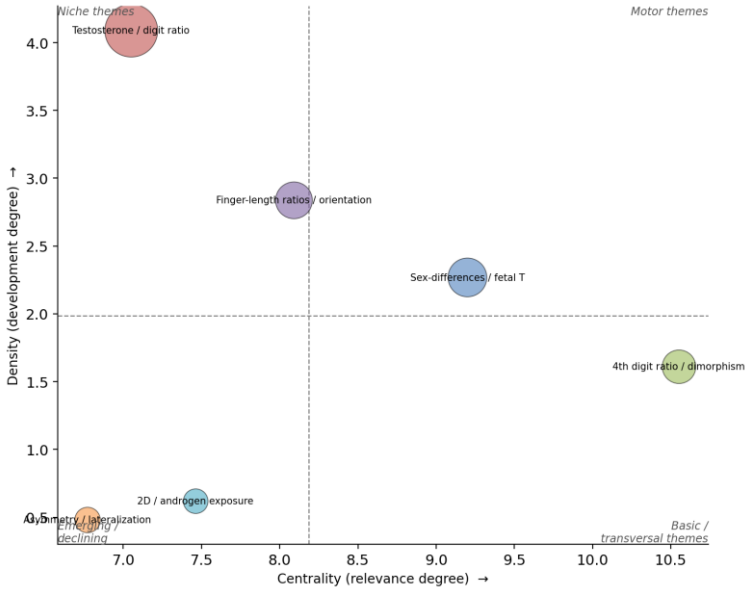


Fig. 5 Thematic (strategic) map of the 2D:4D field. Bubble size is proportional to cluster frequency; the horizontal axis represents centrality (relevance) and the vertical axis density (development).

Thematic evolution and trend topics

Trend-topic analysis, based on the median year of use of high-frequency terms, revealed a clear thematic migration over the study period (Fig. 6). The earliest fronts (median years ~2005–2008) were dominated by basic morphological and developmental terminology—*2D:4D ratio*, *toes*, *relative lengths*, *HOX genes* and *human males*. The middle period (~2010–2013) was characterised by the consolidation of the field's explanatory themes—*congenital adrenal hyperplasia*, *cerebral lateralization*, *sexual selection*, *sexual orientation* and *finger length*.

The most recent fronts (~2014–2017) were dominated by high-frequency, application-oriented and validity-focused terms—*performance*, *testosterone*, *sex-differences* and the numerous spelling variants of the ratio itself—reflecting a maturation of the field from establishing the marker toward testing its behavioural, clinical and psychometric applications.

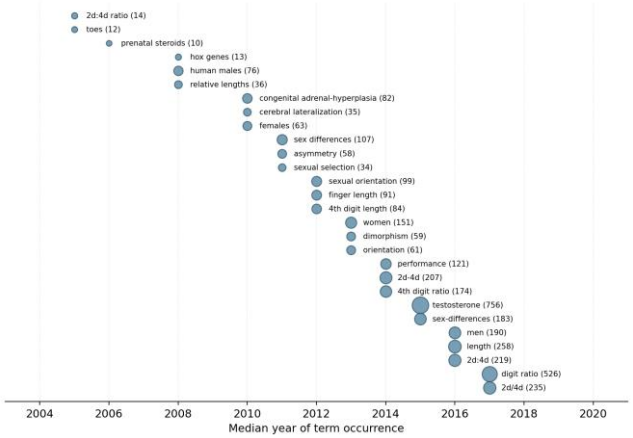


Fig. 6 Trend topics of the 2D:4D field. Each term is plotted at the median year of its occurrence; bubble size is proportional to term frequency.

DISCUSSION

This study provides the first comprehensive bibliometric and knowledge-mapping analysis of the global 2D:4D literature. Three principal findings emerged from the present bibliometric analysis. First, the field is quantitatively mature: from a two-article origin in 1998 it expanded to a stable plateau of around one hundred articles per year, accumulating a mean of 27.5 citations per document and involving more than five thousand authors across 83 countries. Second, its intellectual structure is unusually stable, organised around a single dominant testosterone–digit-ratio core that has remained central since the foundational work of Manning and colleagues (Manning et al., 1998). Third, despite this stability, the field is thematically diversifying, with research fronts migrating from basic morphology and developmental mechanism toward behavioural, clinical, neurodevelopmental and validity-focused applications.

A stable core within a diversifying periphery

The coexistence of a highly central, well-developed core cluster with several actively developing specialised clusters is characteristic of a paradigm-anchored but expanding field. The persistence of testosterone and fetal testosterone as the most frequent substantive terms, together with the continued dominance of the 1998 and 2004 foundational articles in the citation ranking (Lutchmaya et al., 2004; Manning et al., 1998), indicates that the prenatal-androgen hypothesis continues to organise the field conceptually (McIntyre, 2006). At the same time, the emergence of clusters devoted to sexual orientation, gender identity, PCOS, lateralisation and a growing set of clinical outcomes shows that the marker is being exported into an ever wider range of applied questions (Bunevicius, 2018; Grimbos et al., 2010; Hönekopp & Watson, 2010; Lujan et al., 2010; Voracek et al., 2018). This pattern mirrors the trajectory documented in other maturing biomarker literatures, where an initially narrow mechanistic construct becomes a transversal tool across disciplines (McIntyre, 2006).

Sources, geography and collaboration

The concentration of output in a small Bradford core of specialised journals (Bradford, 1985)—led by Personality and Individual Differences, Early Human Development and the American Journal of Human Biology—reflects the hybrid identity of the field at the interface of individual-differences psychology, developmental biology and biological anthropology. The divergence between productivity and impact, with Archives of Sexual Behavior and Hormones and Behavior punching above their output in citation terms, indicates that the field's most influential work clusters in its endocrinological and sexuality-focused outlets.

Geographically, the prominence of Türkiye (fifth worldwide by production) is noteworthy and reflects a vigorous national research community, particularly in clinical, anatomical and psychiatric applications of the ratio. However, the very low international-collaboration rate of several highly productive countries, including Türkiye and Japan, contrasts with the strongly internationalised profile of central and northern European groups. Because international collaboration is consistently associated with higher visibility and impact (Adams, 2013; Glänzel & Schubert, 2001), strengthening cross-national partnerships represents a concrete strategy for increasing the reach of nationally concentrated digit-ratio research.

Methodological caution: homonym contamination

A methodologically important observation concerns the retrieval itself. Even after restriction to original articles, the corpus contained a distinct and sizeable cluster of records from theoretical-physics journals—for example the Journal of High Energy Physics, Nuclear Physics B and Physical Review D—in which the strings "2D/4D" and "2D-4D" denote a duality between two- and four-dimensional gauge theories entirely unrelated to finger length. Additional homonym noise arose from engineering and imaging literature (e.g. "2D/4D" flow MRI and CT reconstruction) and from unrelated legal scholarship on the "single-digit ratio" between punitive and compensatory damages. This contamination, which inflates the raw record count and distorts source and keyword statistics if left uncontrolled, is an inherent hazard of the compact and ambiguous 2D:4D terminology. Future bibliometric and systematic searches on digit ratio should therefore combine the ratio terms with anatomical or endocrine qualifiers (Smoliga et al., 2021), or explicitly exclude physics, engineering and legal Web-of-Science categories, to preserve the disciplinary purity of the corpus.

Limitations

First, the analysis relied on a single database (WoSCC). Although Web of Science has broad coverage, records indexed exclusively in Scopus, PubMed, or regional databases (Mongeon & Paul-Hus, 2016) were not captured, potentially underrepresenting some areas of the literature, including non-English publications. Second, delays in database indexing may underestimate the number of publications and citations in the most recent years. Therefore, the apparent decline in publication output after 2021 should be interpreted with caution. Third, as a descriptive bibliometric study, this analysis did not evaluate the methodological quality of the included studies or the direction and magnitude of their findings. Instead, it characterises the structure, development, and research trends of the literature rather than the scientific validity of the 2D:4D biomarker itself. Finally, as noted above, because the term *2D:4D* is also used in contexts unrelated to digit ratio research, a small number of topically irrelevant records may have remained in the dataset despite the application of document-type and language filters.

CONCLUSION

Over a quarter of a century, research on the second-to-fourth digit ratio has grown into a mature, globally distributed and highly interdisciplinary field, anchored throughout by the prenatal-androgen hypothesis yet increasingly directed toward clinical, neurodevelopmental and psychometric-validity questions. Production is concentrated in a compact set of specialised journals and dominated by a small elite of prolific authors, led by the originator of the modern hypothesis. The knowledge structure is stable at its core and diversifying at its periphery, with trend topics migrating from morphology and developmental mechanism toward behavioural and clinical application. For researchers entering the field—including the strong and growing Turkish community—the principal opportunities lie in strengthening international collaboration, prioritising rigorous replication and validity work, and controlling the homonym contamination that complicates literature retrieval. This bibliometric map offers a reproducible baseline against which the future development of digit-ratio research can be tracked.

Declarations

Funding. This research received no specific grant from any funding agency.

Conflicts of interest. The author declares no conflict of interest.

Data availability. The bibliometric dataset analysed in this study was exported from the Web of Science Core Collection and is available from the author on reasonable request.

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COMPARTMENT-SPECIFIC DISTRIBUTION OF TAS1R1 AND TAS1R2 TASTE RECEPTOR SUBUNITS IN THE FEMALE RAT RECTUM

DİŞİ RAT REKTUMUNDA TAS1R1 VE TAS1R2 TAT RESEPTÖRÜ ALT BİRİMLERİNİN KOMPARTMANA ÖZGÜ DAĞILIMI

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ABSTRACT

Taste receptor subunits are expressed not only in the tongue but also in numerous extraoral tissues. In the gastrointestinal tract, the TAS1R family contributes to luminal nutrient sensing, incretin release and motility; however, the existing map extends from the stomach and small intestine to the distal colon and stops there. The rectum, with its distinctive properties of storage, continence and dense microbial colonisation, lies outside this map. Furthermore, TAS1R1 and TAS1R2 have generally been examined in separate studies rather than mapped comparatively within the same tissue. This study comparatively examined the cellular distribution of the two subunits in the female rat rectum. Rectal tissues from fifteen adult female Sprague-Dawley rats were fixed in 10% neutral buffered formalin, embedded in paraffin, and 5 µm sections were processed by the avidin-biotin-peroxidase method using rabbit polyclonal anti-TAS1R1 and anti-TAS1R2 (both 1:200). Each staining run included a negative control in which the primary antibody was replaced by PBS, and thyroid sections carried as a procedural control tissue. Anti-TAS1R2 immunoreactivity was widespread and cytoplasmic in the crypt epithelial cells and was absent from the stromal compartment. Conversely, anti-TAS1R1 immunoreactivity appeared as focal clusters in the lamina propria and stromal cells and did not stain the crypt epithelium. Neither antibody stained the muscularis mucosae, and no specific immunostaining was observed in the negative controls. The findings show that the two subunits occupy mutually exclusive compartments within the same segment and extend the gastrointestinal chemosensory map to its most distal segment. The segregated distribution suggests that TAS1R1 and TAS1R2 may be present in different cell populations in the rectum rather than within a common heterodimer. The study is descriptive; inference regarding the presence of a functional receptor requires TAS1R3 to be demonstrated separately.

Keywords: Chemoreceptor Cells; Immunohistochemistry; Intestinal Mucosa; Rats, Sprague-Dawley; Receptors, G-Protein-Coupled; Rectum

ÖZET

Tat reseptörü alt birimleri yalnızca dilde değil, çok sayıda ağız dışı dokuda da eksprese edilir. Gastrointestinal sistemde TAS1R ailesinin lüminal besin algısına, inkretin salınımına ve motiliteye katıldığı gösterilmiştir; ancak mevcut haritalama mide ve ince bağırsaktan distal kolona kadar uzanıp orada sonlanmaktadır. Depolama, kontinans ve yoğun mikrobiyal kolonizasyon gibi kendine özgü nitelikleri olan rektum bu haritanın dışındadır. Ayrıca TAS1R1 ve TAS1R2 literatürde genellikle ayrı çalışmalarda ele alınmış, aynı dokuda karşılaştırmalı olarak haritalanmamıştır. Bu çalışmada dişi rat rektumunda iki alt birimin hücresel dağılımı karşılaştırmalı biçimde incelenmiştir. On beş ergin dişi Sprague-Dawley ratın rektum dokuları %10 nötral tamponlu formaldehitte tespit edilmiş, parafine gömülmüş ve 5 µm kesitlere avidin-biyotin-peroksidaz yöntemiyle tavşan poliklonal anti-TAS1R1 ve anti-TAS1R2 (her ikisi 1:200) uygulanmıştır. Her boyama serisine primer antikorun PBS ile değiştirildiği negatif kontrol ve prosedürel kontrol dokusu olarak taşınan tiroit kesitleri dahil edilmiştir. Anti-TAS1R2 immünreaktivitesi kript epitel hücrelerinde yaygın ve sitoplazmik olarak saptanmış, stromal kompartmanda izlenmemiştir.

Anti-TAS1R1 immünreaktivitesi ise bunun tersine lamina propria ve stromal hücrelerde fokal kümeler hâlinde gözlenmiş, kript epitelini boyamamıştır. Muskularis mukozada her iki antikorla da boyanma saptanmamış, negatif kontrollerde spesifik immünboyanma izlenmemiştir. Bulgular, iki alt birimin aynı segment içinde birbirini dışlayan kompartmanlara yerleştiğini göstermekte ve gastrointestinal kemoduyu haritasını en distal segmente taşımaktadır. Ayrışmış dağılım, TAS1R1 ve TAS1R2'nin rektumda ortak bir heterodimer içinde değil, farklı hücre popülasyonlarında bulunabileceğini düşündürmektedir. Çalışma tanımlayıcı olup, işlevsel reseptör varlığına ilişkin çıkarım TAS1R3 alt biriminin ayrıca gösterilmesini gerektirmektedir.
Anahtar Kelimeler: Bağırsak mukozası; G-proteinine kenetli reseptörler; İmmünohistokimya; Kemoreseptör hücreler; Rektum; Sıçanlar, Sprague-Dawley

1. INTRODUCTION

In mammals, sweet and umami perception is mediated by members of the TAS1R family, which belong to the class C G protein-coupled receptor family (Hoon et al., 1999; Pin et al., 2003). A distinction must be drawn at the outset: TAS1R1, TAS1R2 and TAS1R3 are three separate subunits encoded by three independent genes; the functional receptor is not a single subunit but the heterodimer that TAS1R3 forms with one of the other two. TAS1R2/TAS1R3 detects sugars and sweeteners, whereas TAS1R1/TAS1R3 detects L-amino acids (Li et al., 2002; Nelson et al., 2002; Nelson et al., 2001). Studies in TAS1R3-deficient mice demonstrated that TAS1R3 plays a critical role in sweet and umami taste perception, although residual responses to some tastants persisted, suggesting the existence of additional taste-sensing mechanisms (Damak et al., 2003). Transduction proceeds through α-gustducin, phospholipase C-β2 and TRPM5 (Chandrashekar et al., 2006).

The recognition that this machinery is not specific to the oral cavity has changed the framing of the field. Members of the TAS1R and TAS2R families have been demonstrated in airway epithelium, testis, pancreas, heart and the gastrointestinal tract, and the concepts of a “diffuse chemosensory system” and “extraoral taste receptors” have become established for these molecules (Behrens and Meyerhof, 2010; Finger and Kinnamon, 2011; Foster et al., 2014; Lee and Cohen, 2015; Sbarbati and Osculati, 2005). Outside the mouth, the function of these molecules is not taste perception but monitoring of the chemical environment; indeed, the TAS1R1/TAS1R3 heterodimer has been shown to regulate mTORC1 and autophagy by sensing intracellular amino acid sufficiency (Wauson et al., 2012), and TAS1R1 has been shown to control basal calcium and cAMP levels in spermatozoa (Meyer et al., 2012a).

The gastrointestinal tract is the field in which this expansion has been examined in greatest detail. TAS1R2, TAS1R3 and taste signalling proteins have been shown to be expressed in the intestinal epithelium, and this machinery has been shown to link glucose sensing in enteroendocrine cells to SGLT1 expression and GLP-1 release (Bezençon et al., 2007; Dyer et al., 2005; Jang et al., 2007; Margolskee et al., 2007). TAS1R1/TAS1R3 has been reported to stimulate cholecystokinin release by sensing luminal amino acids (Daly et al., 2013), and TAS1R3 has been reported to be localised in brush (tuft) and ghrelin cells in the stomach (Hass et al., 2010). Tuft cells are among the cells carrying these molecules and initiate mucosal immune responses (Gerbe et al., 2012; Howitt et al., 2016). The general framework has been collated in reviews (Depoortere, 2014; Steensels and Depoortere, 2018).

Mapping becomes sparser distally. In the human colon, α-gustducin has been demonstrated in L cells containing PYY and GLP-1 (Rozengurt et al., 2006), TAS2R expression in the large intestine has been associated with secretory responses (Kaji et al., 2009; Latorre et al., 2016), and the most direct evidence for the TAS1R family has been provided by Kendig et al. (2014): TAS1R1/TAS1R3 immunoreactivity was demonstrated in mucosal cells of the distal colon of four species, and a luminal umami stimulus was shown to initiate the peristaltic reflex and to increase the rate of pellet propulsion.

Two gaps nevertheless persist. The first is anatomical: the rectum, the most distal segment of the colorectal transition, lies outside this map. Absorption is of secondary importance in the rectum; its principal roles are storage, continence and management of the defecation reflex. Luminal content dwells here longest, microbial density and the accumulation of fermentation products are at their highest, and mucus production by the crypt epithelium is prominent. These properties suggest that the rectum may carry a chemosensory apparatus of its own. The second is methodological: TAS1R1 and TAS1R2 have generally been addressed in separate studies or through their common partner TAS1R3, and have not been mapped simultaneously in the same section of the same animal.

A subunit-specific antibody recognises only the subunit it targets and does not label TAS1R3; single-subunit designs therefore cannot answer the question of whether the two subunits are present in the same cells or in different cells. An overlapping distribution would point to a single chemosensory cell population, whereas a segregated distribution would point to two separate populations directed at different ligand classes.

The present study addresses these two gaps together; the cellular localisation and compartmental distribution of the TAS1R1 and TAS1R2 subunits in the female rat rectum were compared immunohistochemically in the same sections of the same animal. The original aspect of the study is that this question cannot be answered by single-subunit designs: the question for which an answer is sought is whether the two subunits are present in the same cell population in the rectal mucosa or in populations separate from one another. The study was designed as descriptive; it aims to establish the distribution of the subunits and does not aim at any inference regarding the presence of a functional receptor.

2. STUDY AREA

The study is a descriptive histological and immunohistochemical investigation conducted in an experimental animal model. Animal procedures were carried out at the Kafkas University Experimental Research Application and Research Centre, and tissue processing, staining and microscopic evaluation at the Research Laboratory of the Department of Histology and Embryology, Faculty of Medicine, Ağrı İbrahim Çeçen University.

The region sampled is the rectal segment that, in the rat, extends as the continuation of the colon caudal to the peritoneal reflection and opens into the anal canal. Samples were taken from the portion extending from approximately 1 cm distal to the colorectal transition to the anocutaneous border.

3. MATERIAL AND METHOD

3.1. Experimental Animals and Ethics

Fifteen adult female Sprague-Dawley rats aged 12-18 weeks were used in the study. The animals were housed under a 12 h light/12 h dark cycle with free access to standard pellet chow and water. The Sprague-Dawley strain was preferred because it has a broad body of published baseline data in rodent histology and because, being albino, it does not produce melanin artefact in diaminobenzidine-based immunohistochemistry. All procedures were carried out with the approval of the Kafkas University Local Ethics Committee for Animal Experiments [KAÜ-HADYEK/2026-159, 03.07.2026], in accordance with the principles of European Union Directive 2010/63/EU and the ARRIVE 2.0 guidelines. The conduct of the study in female animals only arises from the fact that the tissues were obtained from a broader experimental series that also covered the female genital system and that additional animal use was avoided in accordance with the 3R principle.

3.2. Anaesthesia and Tissue Sampling

Anaesthesia was achieved by intraperitoneal administration of a combination of ketamine hydrochloride (75 mg/kg) and xylazine hydrochloride (15 mg/kg); euthanasia was performed under deep anaesthesia with a high dose of pentobarbital sodium (i.p.). The rectal segment was dissected, and the thyroid gland was removed from the same animals as procedural control tissue. Samples were cleared of luminal content with cold phosphate-buffered saline and transferred to fixative without delay.

3.3. Tissue Processing and Histological Staining

Tissues were fixed in 10% neutral buffered formaldehyde for 48 h, dehydrated in graded ethanol, cleared in xylene and embedded in paraffin. Serial sections 5 µm thick were taken with a rotary microtome. Haematoxylin-eosin staining was applied according to the standard protocol for general tissue morphology (Fischer et al., 2008). Sections were examined under a Nikon Eclipse i50 trinocular light microscope (Nikon Corporation, Tokyo, Japan) at ×4, ×10, ×20 and ×40 magnifications.

3.4. Immunohistochemistry

Following deparaffinisation and rehydration, heat-induced epitope retrieval was applied in 10 mM sodium citrate buffer (pH 6.0) at 95 °C for 20 min (Shi et al., 1993). Endogenous peroxidase activity was quenched with 3% hydrogen peroxide in methanol for 10 min at room temperature; non-specific binding was blocked with 5% normal serum for 30 min.

Sections were incubated overnight at +4 °C with rabbit polyclonal anti-TAS1R1 (cat. no. BS-8612R; Bioss Inc., Woburn, MA, USA; 1:200) and anti-TAS1R2 (cat. no. BS-9599R; Bioss Inc.; 1:200) primary antibodies. Both antibodies are reported by the manufacturer to be reactive with human, mouse and rat; the working dilutions were determined empirically during optimisation and remained within the range recommended by the manufacturer. Detection used the avidin-biotin-peroxidase complex protocol, with 3,3'-diaminobenzidine as chromogen and Mayer's haematoxylin as counterstain. All sections were processed with the same reagent lots and the same incubation times.

3.5. Controls

Two controls accompanied each staining run. In the negative controls, PBS was applied in place of the primary antibody; all other steps were kept identical. These sections define the contribution of the detection system, endogenous peroxidase and non-specific chromogen deposition to the signal. In addition, thyroid sections taken from the same animals were carried in each run as a procedural control and confirmed that retrieval, detection and chromogen development had worked as expected within that lot.

It must be stated explicitly that the rat thyroid is not an independently validated reference tissue for TAS1R1 or TAS1R2. The extraoral sites in which TAS1R family expression is best documented are the gastrointestinal tract, pancreas, airway, brain, heart and testis (Depoortere, 2014; Lee and Cohen, 2015; Meyer et al., 2012b). Thyroid sections are therefore presented not as a biological positive control but as a procedural control. Furthermore, both primary antibodies are polyclonal reagents with limited independent validation in the published literature, and a single antibody per target was used in this study. The consequences of both points for interpretation are addressed in Section 4.3.

3.6. Microscopic Evaluation and Image Processing

Evaluation was carried out by two independent observers blinded to antibody identity and to each other's assessment. In each section, the crypt epithelium, lamina propria/stroma and muscularis mucosae compartments were scanned separately; the presence, cellular localisation and pattern of distribution of immunoreactivity were recorded descriptively against the matched negative control. Brown colouration derived from diaminobenzidine was accepted as positive immunoreactivity. The study is descriptive by design; immunoreactivity was not quantified and inferential statistics were not applied. Digital micrographs were subjected only to gamma correction and saturation adjustment applied equally to the entire image; no regional or structure-specific intervention was applied and tonal information was not clipped.

4. RESULTS AND DISCUSSION

4.1. Results

In the rectal sections to which anti-TAS1R2 was applied, immunoreactivity was detected in the crypt epithelial cells (Figure 1c, d). The staining was cytoplasmic in character and showed a widespread distribution along the crypt; no positivity was observed in the stromal compartment.

In the sections to which anti-TAS1R1 was applied, the distribution was the reverse of this. Immunoreactivity was observed as focal clusters in the lamina propria and stromal cells (Figure 1a, b); no staining was detected in the crypt epithelium. No immunoreactivity was observed in the muscularis mucosae with either antibody. The two subunits thus displayed a mutually exclusive compartmental distribution within the same segment (Table 1).

No specific immunostaining was observed in any compartment in the negative control sections; only nuclei counterstained with haematoxylin were seen (Figure 1e, f). In the thyroid sections carried as procedural control tissue, stromal staining was detected with both antibodies; the staining obtained with anti-TAS1R1 was more pronounced than that with anti-TAS1R2, and no positivity was observed in the follicular epithelium (Figure 1g-j).

Table 1. Descriptive distribution of immunoreactivity by compartment in the rectum and in the procedural control tissue.

Tissue and compartment	Anti-TAS1R1	Anti-TAS1R2	Negative control
Rectum – crypt epithelium	No staining	Widespread, cytoplasmic	No staining
Rectum – lamina propria / stroma	Focal, clustered	No staining	No staining
Rectum – muscularis mucosae	No staining	No staining	No staining
Thyroid (procedural control) – stroma	Pronounced	Weak	No staining
Thyroid (procedural control) – follicular epithelium	No staining	No staining	No staining

4.2. Discussion

The principal finding of this study is that TAS1R1 and TAS1R2 immunoreactivity is located in mutually exclusive compartments in the female rat rectum: TAS1R2 is epithelial and TAS1R1 is stromal. Because the two subunits have generally been addressed in separate studies in the literature, comparative distribution data within the same section were not available. The segregation itself is more informative than demonstrating the presence of a single subunit; it indicates that the overlapping distribution that would be expected if they were present within a common heterodimer was not observed.

The presence of TAS1R2 immunoreactivity in the crypt epithelium may be read as a distal extension of the data reported from proximal segments. Dyer et al. (2005) and Bezençon et al. (2007) showed that sweet receptor subunits are expressed in solitary cells of the intestinal epithelium; Margolskee et al. (2007) and Jang et al. (2007) established that this machinery links luminal sugar sensing to transporter expression and incretin release. Since the rectum is not a notable absorptive organ, the likely correlate of sensing here is not the regulation of glucose absorption but mucus secretion, fluid-electrolyte balance and local peptide responses. The demonstration of taste receptor-bearing enteroendocrine cells in the human colonic mucosa (Latorre et al., 2016; Rozengurt et al., 2006) supports this reading.

The stromal concentration of TAS1R1 immunoreactivity, by contrast, differs from the mucosal localisation reported in the rat colon by Kendig et al. (2014). Three explanations may be considered. The first is a segmental difference: the rectum is more distal, its microbial load and mucus production are higher, and receptor distribution is known to vary between segments. The second is a difference in functional context: TAS1R1/TAS1R3 does not act in luminal sensing alone; it regulates mTORC1 and autophagy by sensing intracellular amino acid sufficiency (Wauson et al., 2012). Within this framework, the presence of TAS1R1 in the fibroblasts and mononuclear cells of the lamina propria may correspond to a metabolic sensor function independent of luminal sensing. The third is topographical proximity: Kendig et al. (2014) showed that an umami stimulus initiates the peristaltic reflex and stimulates CGRP release, which indicates that TAS1R1 signalling operates in functional adjacency to submucosal nerve endings and connective tissue components.

When the epithelial and stromal findings are evaluated together, it is seen that the rectal mucosa harbours not a single chemosensory cell community but two layers separate from one another: an epithelial layer facing the lumen and carrying TAS1R2, and a stromal layer beneath it carrying TAS1R1. This arrangement suggests that chemical monitoring in the distal intestine may not be limited to luminal content and that the intratissue environment may also be being monitored. The data at hand, however, constitute an observation of distribution; which cell types the layers consist of, whether a functional connection exists between them and whether this arrangement has a physiological correlate remain open. Since tuft cells are known to initiate mucosal immune responses using the taste signalling set (Gerbe et al., 2012; Howitt et al., 2016), whether the stromal clusters overlap with such interaction sites is one of the priority questions. The rectum is thus added to the sequence of mapping extending from the stomach to the small intestine (Hass et al., 2010; Daly et al., 2013) and from there to the distal colon (Kendig et al., 2014).

4.3. Limitations

This study is descriptive in nature. Immunoreactivity was not quantified and no statistical comparison was made. Differences between compartments are therefore presented not as measured quantitative data but as observed distribution patterns. Receptor identity rests solely on immunohistochemical findings. Because the negative control used was based on replacing the primary antibody with PBS, it evaluates only the reliability of the detection system and does not confirm the specificity of the primary antibody. Furthermore, the limited independent validation of polyclonal antibodies and the use of only a single antibody for each target increase the uncertainty regarding antibody specificity. The possibility of non-specific binding cannot be entirely excluded, particularly with respect to stromal TAS1R1 immunoreactivity. Stromal staining has therefore been evaluated as an observational finding, and definitive confirmation requires a peptide pre-adsorption test and additional validation studies in reference tissues containing taste buds. Other limitations of the study include the fact that the phenotype of the immunoreactive cells was not determined, that the TAS1R3 subunit was not evaluated, that the investigation was conducted in female animals only, and that no functional analysis capable of revealing the possible physiological functions of the receptors was performed.

5. CONCLUSIONS

The presence of TAS1R1 and TAS1R2 immunoreactivity in the female rat rectum has been demonstrated, and it has been established that the two subunits are located in mutually exclusive cellular compartments. TAS1R2 is widespread and cytoplasmic in the crypt epithelial cells, whereas TAS1R1 is focal in the lamina propria and stromal cells; no staining was detected in the muscularis mucosae.

On this basis, the study puts forward the following: TAS1R1- and TAS1R2-immunoreactive cells are present in the rectum, their distributions segregate by compartment, and taste receptor subunit expression is not confined to proximal segments. The study does not, however, put forward that a functional TAS1R heterodimer is present in the rectum, that these subunits actually sense luminal content, or that the compartmental segregation has a physiological consequence; each of these claims requires demonstration of TAS1R3 co-occurrence and functional measurement.

At the following stage, semi-quantitative grading of immunoreactivity, confirmation of antibody specificity by peptide pre-adsorption and by reference tissue containing taste buds, evaluation of the TAS1R3 subunit, double labelling with cell type-specific markers, and comparison of the distribution in male animals and in models of experimental colitis, constipation and colorectal carcinogenesis are planned.

6. CONTRIBUTION

Author contributions: Study design, immunohistochemical evaluation and writing of the full-text paper by S.N.P.; tissue processing, sectioning and staining procedures by M.N.G.; microscopic imaging and figure preparation by S.N.P. and M.N.G.; literature search and critical revision by S.N.P. and M.V.B. All authors have read and approved the final version of the manuscript.

Ethics statement: The study was conducted with the approval of the Kafkas University Local Ethics Committee for Animal Experiments, decision no. KAÜ-HADYEK/2026-159 dated 03.07.2026, in accordance with the principles of European Union Directive 2010/63/EU and the ARRIVE 2.0 guidelines.

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Figure Captions

Figure 1. Immunohistochemical staining patterns of TAS1R1 and TAS1R2 in the female rat rectum and in the procedural control tissue. (a, b) Rectum, anti-TAS1R1: immunoreactivity is seen as focal clusters in the lamina propria and stromal cells, and no staining is seen in the crypt epithelium. (c, d) Rectum, anti-TAS1R2: immunoreactivity is widespread and cytoplasmic in the crypt epithelial cells; no positivity was detected in the stromal compartment. (e, f) Negative control (rectal sections in which PBS was applied in place of the primary antibody): no specific immunostaining was observed, only nuclei counterstained with haematoxylin were seen. (g, h) Procedural control tissue, thyroid, anti-TAS1R1: pronounced stromal staining; there is no positivity in the follicular epithelium. (i, j) Procedural control tissue, thyroid, anti-TAS1R2: weaker stromal staining compared with anti-TAS1R1. Avidin-biotin-peroxidase method, diaminobenzidine chromogen, Mayer's haematoxylin counterstain. Scale bar: 100 µm.

HAYVAN VENOMLARINDAN GELİŞTİRİLEN İLAÇLAR: DOĞAL TOKSİNLERDEN MODERN FARMAKOTERAPİYE

DRUGS DEVELOPED FROM ANIMAL VENOMS: FROM NATURAL TOXINS TO MODERN PHARMACOTHERAPY

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ÖZET

Hayvan venomları; peptitler, proteinler, enzimler ve çeşitli biyolojik aktif bileşenler içeren, yüksek moleküler çeşitliliğe sahip doğal kaynaklardır. Bu bileşenlerin belirli reseptörler, iyon kanalları ve enzimler üzerinde yüksek seçicilikle etki gösterebilmesi, venomları modern ilaç keşfi ve geliştirme çalışmaları açısından önemli bir araştırma alanı hâline getirmiştir. Hayvan venomları, modern biyoteknolojik ve farmasötik yaklaşımlar değerlendirildiğinde, yeni terapötik hedefler ve ilaç adayları için önemli bir kaynak olmaya devam etmektedir. Özellikle venom bileşenlerinin farklı moleküler hedeflere yönelik özgün etkileri, çeşitli hastalıkların tedavisinde yeni yaklaşımların geliştirilmesi açısından dikkat çekmektedir. Bu bildiri, potansiyel adayların bilimsel temelini netleştirmeyi ve gelecek araştırma yönlerini belirlemeyi amaçlamaktadır. Bu doğrultuda yılan, akrep, örümcek, koni salyangozu ve arı venomlarında bulunan başlıca etken maddeler ile bunların ilaç geliştirme çalışmalarındaki rolleri mevcut çalışmalar çerçevesinde ele alınmıştır. Bu kapsamda venom bileşenlerinin farmakolojik özellikleri, hedef molekülleri ve terapötik uygulamalara aktarılabilirliği üzerinde durulmuştur. Venom araştırmalarının modern farmakoterapiye katkısını gösteren kaptopril, eptifibatid, tirofiban, zikonotid ve eksenatid gibi ilaçlar; kaynakları, etki mekanizmaları ve terapötik kullanım alanları açısından değerlendirilmektedir. Ayrıca venom kökenli peptitlerin kanser, kronik ağrı, enfeksiyon, inflamasyon ve metabolik hastalıklar gibi farklı alanlardaki tedavi edici potansiyeline dair mevcut veriler değerlendirilmiştir. Bununla birlikte toksisite, biyoyararlanım, proteolitik parçalanma, farmakokinetik özellikler ve hedef dışı etkiler gibi kısıtlayıcı özellikleri ele alınmaktadır. Bunun yanı sıra, venom temelli araştırmaların klinik uygulamalara aktarılmasında karşılaşılan güncel sorunlar ve çözüm olanakları da değerlendirilmiştir. Sonuç olarak hayvan venomlarının modern biyoteknolojik ve farmasötik yaklaşımlarla değerlendirilmesi, yeni terapötik hedeflerin ve ilaç adaylarının keşfi açısından önemli fırsatlar sunmaktadır.

Anahtar Kelimeler: Hayvan venomları, venom kökenli ilaçlar, toksinler, ilaç keşfi, farmakoterapi

ABSTRACT

Animal venoms are natural sources with high molecular diversity, containing peptides, proteins, enzymes, and various active components. Their ability to exert high selectivity on specific receptors, ion channels, and enzymes has made venoms a significant research area for modern drug discovery and development. When assessed through modern biotechnological and pharmaceutical approaches, animal venoms continue to be an important source of new therapeutic targets and drug candidates. In particular, the unique effects of venom components on different molecular targets draw attention for the development of new treatment approaches for various diseases. This presentation aims to clarify the scientific basis of potential candidates and to define directions for future research. Accordingly, the major active constituents found in the venoms of snakes, scorpions, spiders, cone snails, and bees are discussed within the framework of current studies and their roles in drug development.

Within this scope, the pharmacological properties, target molecules, and translatability to therapeutic applications of venom components are highlighted. The contribution of venom-derived research to modern pharmacotherapy is illustrated by drugs such as captopril, eptifibatide, tirofiban, ziconotide, and exenatide; their sources, mechanisms of action, and therapeutic uses are evaluated. In addition, existing data on the therapeutic potential of venom-derived peptides in cancer, chronic pain, infections, inflammation, and metabolic diseases are reviewed. However, restrictive properties such as toxicity, bioavailability, proteolytic degradation, pharmacokinetic characteristics, and off-target effects are discussed. Furthermore, current issues and potential solutions for translating venom-based research into clinical applications are evaluated. In conclusion, evaluating animal venoms with modern biotechnological and pharmacological approaches offers important opportunities for the discovery of new therapeutic targets and drug candidates.
Keywords: Animal venoms, venom-derived drugs, toxins, drug discovery, pharmacotherapy

GİRİŞ

Hayvan venomları, toksik etkilerinin yanı sıra farklı biyolojik hedefler üzerinde etkili olabilen çok sayıda aktif molekül içermeleri nedeniyle ilaç keşfi açısından önemli doğal kaynaklar arasında değerlendirilmektedir. Venomların bileşimi; peptitler, proteinler, enzimler ve düşük molekül ağırlıklı bileşikler gibi farklı moleküler sınıfların bir araya gelmesiyle oluşmakta ve bu moleküler çeşitlilik, venomların çok sayıda biyolojik süreç üzerinde etkili olabilmesini sağlamaktadır (Morsy et al., 2023; Freuville et al., 2024).

Venom bileşenlerinin farmakolojik açıdan dikkat çekici özelliklerinden biri, iyon kanalları, reseptörler ve enzimler gibi moleküler hedeflerle etkileşebilmeleridir. Özellikle venom peptitlerinin belirli iyon kanalı alt tiplerini seçici biçimde düzenleyebilmesi veya değiştirebilmesi, bu moleküllerin hem biyolojik mekanizmaların araştırılması hem de yeni farmakolojik ajanların geliştirilmesinde kullanılmasına olanak sağlamıştır (King, 2011; Muttenthaler et al., 2021). Bu etkileşimler, hedef moleküllerin aktivitesinin baskılanması veya değiştirilmesi yoluyla farklı biyolojik sonuçların ortaya çıkması yoluyla gerçekleşmektedir.

Venom araştırmalarında genomik, transkriptomik ve proteomik teknolojilerin yaygınlaşması, venomlarda ki moleküler çeşitliliğinin daha kapsamlı şekilde incelenebilmesini sağlamıştır. Venomik yaklaşımlar sayesinde venom bileşenlerinin moleküler profilleri daha ayrıntılı olarak ortaya konabilmekte ve yeni biyoaktif moleküllerin araştırılmasına yönelik veri elde edilebilmektedir (Morsy et al., 2023; Roman-Ramos & Ho, 2024).

Venom araştırmalarının modern farmakoterapiye katkısı, farklı hayvan gruplarından elde edilen moleküler bilgilerin klinik kullanıma ulaşmış ilaçların geliştirilmesinde ve kullanılmasında açıkça görülmektedir. Kaptoprilin geliştirilmesi, *Bothrops jararaca* venomundan elde edilen bradikinin-potansiyalize edici peptitlerin ACE üzerindeki etkilerine ilişkin çalışmalarla ilişkilidir (Ferreira et al., 1970; Cushman & Ondetti, 1991). Zikonotid ise denizel koni salyangozu *Conus magus* venomunda bulunan ω-MVIIA'nın sentetik eşdeğeri olarak geliştirilmiştir (Miljanich, 2004). Eptifibatid ve tirofiban ise yılan venom disintegrinlerinin yapısal özelliklerinden yararlanılarak geliştirilen sentetik antitrombosit ajanlardır; Eptifibatid Barbourin, Tirofiban ise Echistatin temel alınarak tasarlanmıştır (Gan et al., 1988; Scarborough et al., 1991; Bhatt & Topol, 2000). Venom araştırmaları yalnızca yeni biyoaktif moleküllerin keşfine değil, aynı zamanda bu moleküllerin farmakolojik özelliklerinin geliştirilmesine yönelik optimizasyon çalışmalarına da odaklanmaktadır (Freuville et al., 2024; Kim et al., 2025).

Bu bildirinin amacı, hayvan venomlarında bulunan biyolojik aktif moleküllerin ilaç keşfi ve geliştirilmesinde ki rolünü değerlendirmektir. Bu kapsamda venom bileşenlerinin moleküler hedefleri ve etki mekanizmaları, klinik kullanıma ulaşmış venom bileşenlerinden geliştirilen veya bu bileşenlerden esinlenerek tasarlanan ilaçlar ile farklı hayvan gruplarından elde edilen moleküllerin terapötik potansiyeli güncel literatür doğrultusunda ele alınmaktadır.

ARAŞTIRMA VE BULGULAR

1. HAYVAN VENOMLARININ BİYOLOJİK VE FARMAKOLOJİK TEMELİ

1.1. Hayvan Venomlarının Biyokimyasal Bileşimi

Hayvan venomları, milyonlarca yıllık evrimsel süreç boyunca avlanma, savunma ve diğer biyolojik işlevlere uyum sağlayacak şekilde çeşitlenmiş karmaşık biyolojik karışımlardır. Venomların bileşimi türler arasında önemli farklılıklar gösterebilmekte ve tek bir venom çok sayıda farklı moleküler bileşen içerebilmektedir (Freuville et al., 2024).

Venomların biyokimyasal yapısında peptitler, proteinler, enzimler ve düşük molekül ağırlıklı bileşikler gibi farklı moleküller bulunmaktadır (Freuville et al., 2024). Bunlar farklı biyolojik hedeflerle etkileşerek venomların özgün farmakolojik ve toksikolojik etkilerinin ortaya çıkmasına katkıda bulunmaktadır (Freuville et al., 2024).

Venomların önemli biyoaktif bileşenleri arasında peptitler öne çıkmaktadır. Özellikle disülfit bağlarıyla stabilize edilen venom peptitleri, belirli moleküler hedeflere yüksek seçicilikle bağlanmakta ve güçlü biyolojik aktivite gösterebilmektedir. Bu yapısal özellikler, bazı venom peptitlerinin proteolitik yıkıma karşı direnç göstermesine de katkıda bulunmaktadır (Freuville et al., 2024).

Proteinler de venomların biyolojik etkilerinde önemli rol oynayan makromoleküllerdir. Özellikle yılan venomlarında farklı protein ve peptit ailelerinin, venom bileşiminin önemli bir kısmını oluşturduğu gösterilmiştir. Bu gruplar arasında Fosfolipaz A_2 (PLA_2), Yılan Venom Metalloproteinazları (SVMP), Yılan Venom Serin Proteinazları (SVSP), L-Amino Asit Oksidazlar (LAAO), Disintegrinler ve diğer protein aileleri bulunmaktadır (Tasoulis & Isbister, 2017).

Venomlarda bulunan enzimler, özellikle yılan venomlarının biyolojik etkilerinde önemli rol oynayan bileşenler arasındadır. Fosfolipaz A_2, Metalloproteinazlar, serin Proteinazlar ve L-Amino Asit Oksidazlar farklı biyolojik süreçleri etkileyebilmekte; bu nedenle yılan venomlarının toksikolojik ve farmakolojik özelliklerinin araştırılmasında önemli hedefler oluşturmaktadır (Tasoulis & Isbister, 2017).

Venomlar yalnızca peptit ve proteinlerden oluşmaz; düşük molekül ağırlıklı bileşikler ve diğer küçük moleküller de venom bileşiminde bulunabilmektedir (Freuville et al., 2024). Bu bileşenlerin venomun toplam biyolojik aktivitesine katkıda bulunabileceği bildirilmektedir (Freuville et al., 2024).

Venom bileşiminin dağılımı hayvan grupları arasında belirgin farklılıklar gösterebilmektedir. Yılan venomlarında enzim ve protein aileleri önemli bir yer tutarken, akrep ve örümcek venomlarında iyon kanallarını hedefleyen peptitler öne çıkmaktadır. Koni salyangozlarının venomları ise çok sayıda farklı Konotoksin içermekte ve bu peptitler iyon kanalları ile G proteinine kenetli reseptörler gibi çeşitli nöronal hedefleri seçici biçimde etkileyebilmektedir (Freuville et al., 2024; Robinson & Norton, 2014; Terlau & Olivera, 2004).

1.2.Venom Bileşenlerinin Moleküler Hedefleri

Hayvan venomlarında bulunan biyoaktif moleküllerin farmakolojik açıdan dikkat çekici özelliklerinden biri, farklı moleküler hedeflerle seçici biçimde etkileşebilmeleridir. Venom peptitleri ve proteinleri; iyon kanalları, reseptörler ve enzimler başta olmak üzere çeşitli biyolojik hedefler üzerinde etkili olabilmektedir. Bu hedef çeşitliliği, venom bileşenlerinin hem fizyolojik mekanizmaların araştırılmasında hem de yeni farmakolojik ajanların geliştirilmesinde kullanılmalarına olanak sağlamaktadır (Freuville et al., 2024).

Venom bileşenlerinin önemli hedefleri arasında iyon kanalları yer almaktadır. Voltaj kapılı Sodyum (Na_v), Potasyum (K_v) ve Kalsiyum (Ca_v) kanalları, farklı venom peptitleri tarafından hedeflenebilen başlıca iyon kanalları arasında bulunmaktadır. Bu kanalların sinir iletimi, ağrı algısı ve hücresel uyarılabilirlik teki rolleri nedeniyle, iyon kanallarını etkileyen venom peptitleri nörofarmakolojik araştırmalarda önemli araçlar olarak kullanılmaktadır (Freuville et al., 2024; Terlau & Olivera, 2004; Robinson & Norton, 2014). Özellikle konotoksinler, belirli iyon kanalı alt tiplerini seçici biçimde modüle edebilen venom peptitlerinin önemli örneklerini oluşturmaktadır (Terlau & Olivera, 2004).

Bir diğer önemli hedef grubu G proteinine kenetli reseptörlerdir (GPCR'ler)**.** Venom kaynaklı bazı toksinler, GPCR'lerin aktivitesini agonist, antagonist veya allosterik mekanizmalar üzerinden etkileyebilmektedir. Bu özellik, venom bileşenlerinin reseptör işlevlerinin araştırılmasında ve yeni farmakolojik ligandların geliştirilmesinde kullanılmasına olanak sağlamaktadır (Freuville et al., 2024). Venom toksinlerinin GPCR'lerle etkileşimi, bu moleküllerin yüksek afinite ve seçicilik özellikleri nedeniyle ayrıca farmakolojik açıdan araştırılmaktadır (Freuville et al., 2024).

Venom bileşenlerinin etki gösterdiği diğer önemli hedefler arasında enzimler bulunmaktadır. Özellikle anjiyotensin dönüştürücü enzim (ACE) ile ilişkili araştırmalar, venom bileşenlerinin ilaç geliştirme alanındaki en bilinen örneklerinden birini oluşturmaktadır. *Bothrops jararaca* venomundan elde edilen Bradikinin-potansiyalize edici peptitlerin ACE üzerindeki etkilerine ilişkin çalışmalar, daha sonra Kaptopril gibi ACE inhibitörlerinin geliştirilmesine temel oluşturan araştırma sürecinin önemli basamaklarından biri olmuştur (Ferreira et al., 1970; Cushman & Ondetti, 1991).

İntegrinler de özellikle yılan venomlarının farmakolojik açıdan önemli hedefleri arasındadır. Venom disintegrinleri, trombosit yüzeyindeki αIIbβ3 integrini ile etkileşerek fibrinojen aracılı trombosit agregasyonunu engelleyebilmektedir. Bu özellik, venom disintegrinlerinin antitrombosit ilaç geliştirme çalışmalarında moleküler şablon olarak kullanılmasına katkı sağlamıştır (Gan et al., 1988; Scarborough et al., 1991). Eptifibatid ve Tirofiban, bu yaklaşımın klinik kullanıma ulaşmış örnekleri arasında yer almaktadır (Bhatt & Topol, 2000).

Bunların yanı sıra venom bileşenleri, farklı reseptörler ve hücresel sinyal mekanizmaları üzerinde de etkili olabilmektedir. Bu etkileşimler; hücre proliferasyonu, inflamasyon, bağışıklık yanıtı ve hücresel ölüm gibi çeşitli biyolojik süreçlerin araştırılmasında venom bileşenlerinin kullanılmasına temel oluşturmaktadır (Freuville et al., 2024; Kim et al., 2025). Bununla birlikte, bir venom bileşeninin belirli bir moleküler hedef üzerinde biyolojik aktivite göstermesi, tek başına klinik kullanım için yeterli kanıt oluşturmamaktadır. Terapötik değerlendirme için etkinlik, güvenlilik, seçicilik ve farmakokinetik özelliklerin ayrıca ortaya konması gerekmektedir (Freuville et al., 2024; Kim et al., 2025).

1.3. Venom Bileşenlerinin Etki Mekanizmaları

Hayvan venomlarında bulunan biyoaktif moleküller, farklı biyolojik hedeflerle etkileşime girerek hücresel ve fizyolojik süreçleri değiştirebilmektedir. Bu etkiler; iyon kanallarının, reseptörlerin ve enzimlerin aktivitesinin düzenlenmesi gibi çeşitli moleküler mekanizmalar üzerinden ortaya çıkmaktadır. Venom bileşenlerinin bu hedeflere yönelik seçici etkileri, toksikolojik özelliklerinin yanı sıra farmakolojik araştırmalar açısından da önem taşımaktadır (Freuville et al., 2024).

Venom bileşenlerinin başlıca etki mekanizmalarından biri iyon kanallarının modülasyonudur**.** Çeşitli venom peptitleri Voltaj Kapılı Sodyum (Na_v), Potasyum (K_v) ve Kalsiyum (Ca_v) kanallarının yanı sıra Asit-duyarlı İyon Kanalları (ASIC) ve Geçici Reseptör Potansiyeli (TRP) Kanallarıyla etkileşebilmektedir. Bu etkileşimler kanalın açılma-kapanma özelliklerini veya iyon akışını değiştirerek sinir iletimi, nörotransmitter salınımı ve ağrı sinyallerinin oluşumu gibi süreçleri etkileyebilmektedir (Freuville et al., 2024). İyon kanallarının hedeflenmesi, özellikle nörolojik araştırmalar ve ağrı mekanizmalarının anlaşılması açısından venom peptitlerini önemli moleküler araçlar hâline getirmiştir (Terlau & Olivera, 2004; Rodríguez de la Vega & Possani, 2005).

Bu mekanizmanın klinik uygulamaya ulaşmış örneklerinden biri Zikonotiddir. Deniz koni salyangozu (*Conus magus*) venomunda bulunan ω-MVIIA'nın sentetik karşılığı olan Zikonotid, Nöronal N-Tipi Voltaj Bağımlı Kalsiyum Kanallarını seçici biçimde bloke ederek ağrı iletiminde görev alan nöronların aktivitesini azaltmaktadır (Miljanich, 2004). Böylece venom kaynaklı bir peptidin belli bir iyon kanalını hedefleyen etki mekanizması klinik bir ilacın geliştirilmesinde temel oluşturabileceği gösterilmiştir (Freuville et al., 2024).

Venom bileşenlerinin bir diğer önemli etki mekanizması reseptörlerin düzenlenmesidir**.** Bazı venom peptitleri G proteinine kenetli reseptörler (GPCR'ler), Nikotinik Asetilkolin Reseptörleri ve diğer membran reseptörleriyle etkileşerek hücre içi sinyal iletimini değiştirebilmektedir. Bu etkileşimlerin sonucunda ikinci haberci sistemler, iyon akışı ve hücresel yanıtlar üzerinde değişiklikler meydana gelmektedir (Freuville et al., 2024). Özellikle belli reseptör alt tiplerine yönelik yüksek seçicilik gösteren venom peptitleri, reseptör işlevlerinin araştırılmasında önemli moleküler araçlar olarak kullanılmaktadır.

Enzimlerin inhibisyonu veya aktivitelerinin değiştirilmesi de venom bileşenlerinin önemli etki mekanizmaları arasındadır. Bu mekanizmanın en iyi bilinen örneklerinden biri, *Bothrops jararaca* venomundaki Bradikinin-Potansiyalize Edici Peptitler ile Anjiyotensin Dönüştürücü Enzim (ACE) arasındaki etkileşimdir.

Bu peptitler üzerinde gerçekleştirilen çalışmalar, ACE'nin hedeflenmesine dayalı ilaç geliştirme sürecine katkı sağlamış ve Kaptoprilin geliştirilmesine temel oluşturmuştur (Ferreira et al., 1970; Cushman & Ondetti, 1991). Bu örnek, venom bileşenlerinin doğrudan ilaç olarak kullanılmasının yanı sıra, yeni ilaçların tasarımında yapısal ve farmakolojik model olarak da değerlendirilebileceğini göstermektedir.

Yılan venomlarında bulunan Disintegrinler ise trombosit agregasyonunun düzenlenmesinde rol oynayan İntegrinleri hedeflemektedir. Örneğin Barbourin, trombosit yüzeyindeki GPIIb/IIIa olarak da adlandırılan αIIbβ3 integrinine özgül olarak bağlanabilen bir venom peptidi olarak tanımlanmıştır (Scarborough et al., 1991). Bu tür moleküllerin yapısal özelliklerinden yararlanılarak geliştirilen Eptifibatid ve Tirofiban gibi αIIbβ3 inhibitörleri, venom bileşenlerinin antitrombosit ilaç geliştirilmesinde ki önemini ortaya koymaktadır (Freuville et al., 2024; Bhatt & Topol, 2000).

Venom bileşenleri ayrıca hücre içi sinyal yolaklarını etkileyerek proliferasyon, apoptozis, inflamasyon ve bağışıklık yanıtı gibi süreçlerin düzenlenmesine katkıda bulunabilmektedir. Bu nedenle venom kaynaklı moleküller, özellikle kanser ve inflamatuvar hastalıklarla ilişkili biyolojik mekanizmaların araştırılmasında da incelenmektedir (Freuville et al., 2024; Kim et al., 2025).

1.4. Modern Venom Yaklaşımları ve Venom bilimi Yaklaşımı

Hayvan venomlarının karmaşık moleküler yapısının ortaya çıkarılmasında genomik, transkriptomik, proteomik ve biyoinformatik yöntemlerin birlikte kullanılması önemli olanaklar sağlamıştır. Bu yaklaşımlar, venom bileşenlerinin daha kapsamlı biçimde tanımlanmasına, toksin üretimiyle ilişkili moleküler süreçlerin araştırılmasına ve venom çeşitliliğinin daha ayrıntılı biçimde incelenmesine katkıda bulunmaktadır (Roman-Ramos & Ho, 2024; Sunagar et al., 2016).

Bu bütünleşik araştırma yaklaşımı venom bilimi olarak adlandırılmaktadır. Venom bilimi, venomun moleküler yapısının kapsamlı biçimde incelenmesi amacıyla genomik, transkriptomik ve proteomik verilerin birlikte değerlendirilmesini ifade etmektedir. Bu yaklaşım, venom bileşenlerinin belirlenmesinin yanı sıra venomun biyolojik özellikleri ve moleküler çeşitliliği hakkında daha kapsamlı bilgi elde edilmesine olanak sağlamaktadır (Sunagar et al., 2016; Freuville et al., 2024).

Genomik ve transkriptomik çalışmalar, venom üretimiyle ilişkili genlerin ve toksin gen ailelerinin araştırılmasına olanak sağlamaktadır. Özellikle yeni nesil dizileme teknolojileri, venom bezlerinde ifade edilen genlerin incelenmesine ve farklı türler arasındaki moleküler farklılıkların değerlendirilmesine katkıda bulunmaktadır. Transkriptomik verilerin proteomik analizlerle birlikte değerlendirilmesi ise gen düzeyindeki bilgilerin venomda bulunan protein ve peptit bileşenleriyle ilişkilendirilmesini kolaylaştırmaktadır (Roman-Ramos & Ho, 2024; Sunagar et al., 2016).

Proteomik analizler, venom bileşenlerinin doğrudan karakterizasyonunda önemli bir yere sahiptir. Kütle spektrometrisi ve kromatografik yöntemler kullanılarak venom içerisindeki peptit ve proteinlerin moleküler özellikleri incelenebilmekte ve farklı bileşenlerin tanımlanması mümkün olmaktadır. Bu yöntemler, özellikle kompleks venom karışımlarının analiz edilmesinde ve bileşenlerin moleküler profillerinin ortaya çıkarılmasında kullanılmaktadır (Roman-Ramos & Ho, 2024).

Venom araştırmalarında elde edilen yüksek miktardaki genomik, transkriptomik ve proteomik verilerin değerlendirilmesinde biyoinformatik yöntemler de önemli bir rol üstlenmektedir. Dizi karşılaştırmaları, veri tabanı analizleri ve hesaplamalı yaklaşımlar, toksinlerin moleküler özelliklerinin araştırılmasına ve farklı venom bileşenleri arasındaki ilişkilerin incelenmesine yardımcı olmaktadır (Roman-Ramos & Ho, 2024).

Modern venom araştırmalarında yapısal biyoloji yöntemlerinden de yararlanılmaktadır. Toksinlerin hedef moleküllerle etkileşimlerinin yapısal düzeyde incelenmesi, molekül-hedef ilişkilerinin daha ayrıntılı anlaşılmasına katkı sağlamaktadır. Yapısal bilgiler, venom bileşenlerinin moleküler özelliklerinin değerlendirilmesinde ve yeni terapötik adayların araştırılmasında kullanılabilmektedir (Roman-Ramos & Ho, 2024; Freuville et al., 2024).

Venom bilimi yaklaşımının ilaç keşfi açısından önemli katkılarından biri, çok sayıda venom bileşeninin sistematik biçimde incelenmesine ve farmakolojik açıdan ilgi taşıyan adayların belirlenmesine olanak sağlamasıdır.

2. Venom Kökenli İlaçların Geliştirilme Süreci

Venom kökenli bir molekülün terapötik bir ilaca dönüştürülmesi, doğal venom bileşeninin tanımlanmasından uygun adayların klinik değerlendirilmesine kadar uzanan çok aşamalı bir süreçtir. Bu süreçte öncelikle biyolojik aktivite gösteren aday molekül belirlenmekte, moleküler hedefi ve etki mekanizması araştırılmakta, ardından farmakolojik özellikleri ve güvenlilik profili değerlendirilmektedir (Morsy et al., 2023).

Doğal venom bileşenlerinin doğrudan ilaç olarak kullanılabilmesi her zaman mümkün değildir. Özellikle peptit ve protein yapısındaki adaylarda proteolitik yıkım, düşük biyoyararlanım ve farmakokinetik sınırlılıklar gibi sorunlar ortaya çıkabilmektedir. Bu nedenle aday moleküllerin yapısal ve farmakolojik özelliklerinin geliştirilmesi, uygun formülasyonların oluşturulması ve gerekli klinik öncesi değerlendirmelerin yapılması ilaç geliştirme sürecinin önemli aşamalarını oluşturmaktadır (Muttenthaler et al., 2021).

Venom kaynaklı ilaçların geliştirilmesinde bir diğer önemli yaklaşım, doğal molekülün yapısının veya biyolojik etkisinin temel alınarak yeni bir terapötik molekül tasarlanmasıdır. Kaptoprilin geliştirilmesi, *Bothrops jararaca* venomundan elde edilen Bradikinin-Potansiyalize Edici Peptitlerin ACE inhibisyonuna ilişkin bulgularından yararlanılması bakımından bu yaklaşımın erken ve önemli örneklerinden biridir (Ferreira et al., 1970; Cushman & Ondetti, 1991).

Venom kökenli ilaç geliştirme süreci genel olarak aday molekülün keşfi ve karakterizasyonu, hedef ve etki mekanizmasının belirlenmesi, yapısal veya farmakolojik optimizasyon, klinik öncesi değerlendirme ve uygun adaylar için klinik araştırmalar gibi birbirini izleyen aşamalardan oluşmaktadır. Bu aşamalar boyunca aday molekülün etkinliğinin yanı sıra seçicilik, güvenlilik, stabilite ve farmakokinetik özellikleri de değerlendirilmekte; elde edilen sonuçlara göre molekülün bir sonraki geliştirme aşamasına geçip geçemeyeceği belirlenmektedir (Freuville et al., 2024).

2.1. Venomdan İlaca Giden Araştırma Basamakları

İlk aşamada venom örnekleri uygun koşullarda toplanmakta ve analitik incelemelere hazırlanmaktadır. Kromatografik ayırma yöntemleri ve kütle spektrometrisi gibi teknikler kullanılarak venom içerisindeki peptit, protein, enzim ve diğer bileşenler karakterize edilmektedir. Bu analizler, venom bileşenlerinin moleküler özelliklerinin ortaya çıkarılmasına ve biyolojik aktivite açısından incelenebilecek adayların belirlenmesine temel oluşturmaktadır (Roman-Ramos & Ho, 2024).

Aday bileşenlerin belirlenmesinin ardından biyolojik aktiviteleri ve farmakolojik özellikleri araştırılmaktadır. İn vitro deneylerde moleküllerin iyon kanalları, reseptörler ve enzimler gibi farklı moleküler hedefler üzerindeki etkileri incelenebilmekte; elde edilen sonuçlara göre ileri araştırmalar için uygun adaylar seçilmektedir. Bu aşamada biyolojik etkinliğin yanı sıra hedef seçiciliği ve güvenlilik açısından ortaya çıkabilecek sorunlar da değerlendirilmektedir (Kim et al., 2025; Morsy et al., 2023).

Seçilen aday molekülün etki mekanizmasının ve moleküler hedefinin belirlenmesi, geliştirme sürecinin önemli aşamalarından biridir. Molekülün hangi hedefle etkileştiği ve bu etkileşimin biyolojik yanıtları nasıl değiştirdiği deneysel çalışmalarla araştırılmaktadır. Moleküler hedefin ve etki mekanizmasının ayrıntılı biçimde ortaya konulması, aday molekülün farmakolojik özelliklerinin değerlendirilmesine katkı sağlamaktadır (Kim et al., 2025; Morsy et al., 2023).

Doğal venom bileşenleri her zaman doğrudan ilaç olarak kullanılmaya uygun özelliklere sahip değildir. Özellikle peptit yapısındaki adaylarda proteolitik parçalanma, düşük biyoyararlanım ve kısa plazma yarı ömrü gibi sınırlayıcı özellikler görülebilmektedir. Bu nedenle aday moleküllerin yapısal ve farmakolojik özelliklerinin geliştirilmesine yönelik çeşitli optimizasyon yaklaşımları uygulanabilmektedir. Bu tür modifikasyonlar, moleküllerin stabilitesinin ve farmakokinetik özelliklerinin iyileştirilmesine katkı sağlayabilmektedir (Muttenthaler et al., 2021).Yapısal veya farmakolojik özellikleri geliştirilen adaylar daha sonra klinik öncesi araştırmalarda değerlendirilmektedir. Bu aşamada uygun hücre ve hayvan modellerinde etkinlik, toksisite, güvenlilik, farmakokinetik ve farmakodinamik özellikler incelenmektedir. Yeterli etkinlik ve kabul edilebilir güvenlilik profili gösteren adaylar, gerekli koşulları karşılamaları durumunda insanlarda yürütülen klinik araştırmalara ilerleyebilmektedir (Freuville et al., 2024).

Klinik araştırmaların temel amacı, aday molekülün insanlardaki güvenliliğini ve terapötik etkinliğini değerlendirmektir.

Klinik geliştirme sürecinde farklı aşamalarda güvenlilik, doz ve terapötik etki araştırılmakta; elde edilen sonuçlara göre adayın geliştirme sürecinin sürdürülüp sürdürülmeyeceğine karar verilmektedir. Başarılı sonuçlar elde edilmesi durumunda ilaç adayı, ilgili düzenleyici kurumların değerlendirmesine sunulabilmektedir (Freuville et al., 2024).

2.2. Venom Kökenli İlaç Geliştirmede Güncel Yaklaşımlar

Günümüzde venom kökenli ilaç geliştirme çalışmaları yalnızca doğal bileşenlerin tanımlanmasına değil, aynı zamanda bu moleküllerin yapısal ve farmakolojik özelliklerinin ayrıntılı biçimde incelenmesine ve geliştirilmesine de odaklanmaktadır. Özellikle yapısal biyoloji, biyoinformatik ve peptit mühendisliği alanlarındaki gelişmeler, venom bileşenlerinin ilaç geliştirme açısından daha kapsamlı biçimde değerlendirilmesine olanak sağlamaktadır (Roman-Ramos & Ho, 2024; Muttenthaler et al., 2021).

Yapısal biyoloji yöntemleri, venom bileşenleri ile hedef moleküller arasındaki etkileşimlerin moleküler düzeyde incelenmesine olanak sağlamaktadır. Kriyo-elektron mikroskobu (cryo-EM), X-ışını kristalografisi ve diğer yapısal analiz yöntemlerinden elde edilen bilgiler, toksinlerin yapılarının ve hedef moleküllerle etkileşimlerinin daha ayrıntılı biçimde anlaşılmasına katkıda bulunmaktadır (Roman-Ramos & Ho, 2024). Bu bilgiler, venom bileşenlerinin yapı-fonksiyon ilişkilerinin değerlendirilmesinde ve yeni terapötik adayların araştırılmasında kullanılabilmektedir.

Biyoinformatik ve hesaplamalı yöntemler de venom bileşenlerinin araştırılmasında önemli araçlar hâline gelmiştir. Protein dizilerinin karşılaştırılması, protein yapılarının öngörülmesi ve moleküler etkileşimlerin modellenmesi gibi yaklaşımlar, venom bileşenlerinin özelliklerinin araştırılmasına ve aday moleküllerin önceliklendirilmesine yardımcı olabilmektedir (Roman-Ramos & Ho, 2024). Bununla birlikte, hesaplamalı yöntemlerle elde edilen sonuçların biyolojik işlev açısından değerlendirilmesi için deneysel doğrulama gerekmektedir.

Güncel araştırmaların önemli bir diğer yönünü peptit mühendisliği oluşturmaktadır. Doğal venom peptitlerinin yapısında gerçekleştirilen kontrollü değişiklikler ve sentetik analogların geliştirilmesi yoluyla peptitlerin farmakolojik özelliklerinin iyileştirilmesi amaçlanmaktadır. Bu yaklaşımlar; stabilite, seçicilik, biyoyararlanım ve diğer farmakolojik özelliklerin geliştirilmesine yönelik araştırmalarda kullanılmaktadır (Muttenthaler et al., 2021). Böylece doğal venom peptitlerinin ilaç geliştirme sürecinde karşılaşılan bazı sınırlılıklarının azaltılması hedeflenmektedir.

Bunun yanında venom bileşenlerinin yapısal ve biyolojik özelliklerinden yararlanılarak yeni ilaç tasarımlarına öncülük eden moleküler modeller geliştirilmesi de önemli bir araştırma yaklaşımıdır. Kaptoprilin geliştirilmesi, venom kaynaklı bir peptidin doğrudan ilaç olarak kullanılmasından ziyade, biyolojik etkisinin ve hedef etkileşiminin yeni bir ilaç tasarımına temel oluşturabileceğini gösteren erken örneklerden biridir (Ferreira et al., 1970; Cushman & Ondetti, 1991). Bu yaklaşım, doğal venom bileşenlerinden elde edilen moleküler bilgilerin yeni terapötik adayların tasarımında kullanılabileceğini göstermektedir.

Bu güncel yaklaşımlar, venom bileşenlerinin yalnızca doğal toksinler olarak incelenmesinden, yapı ve işlev bilgilerinin birlikte değerlendirildiği daha kapsamlı bir ilaç keşfi yaklaşımına geçişi göstermektedir (Muttenthaler et al., 2021; Roman-Ramos & Ho, 2024).

3. Venom Bileşenlerinden Esinlenilerek Geliştirilen Klinik Kullanımdaki İlaçlar

3.1. Kaptopril

Kaptopril, hayvan venomlarından elde edilen biyolojik bilgilerden yararlanılarak geliştirilen en önemli ilaç örneklerinden biridir. İlacın geliştirilme süreci, *Bothrops jararaca* venomunda bulunan Bradikinin-Potansiyalize Edici Peptitlerin (Bradykinin Potentiating Peptides; BPPs) tanımlanmasıyla başlayan araştırmalara dayanmaktadır (Ferreira et al., 1970). Bu çalışmaların ardından, venom peptitlerinin ACE üzerindeki etkilerinden yararlanılarak ağızdan kullanılabilen sentetik bir ACE inhibitörü olan Kaptopril geliştirilmiştir (Cushman & Ondetti, 1991; Freuville et al., 2024).

Kaptopril, doğal venom peptidinin doğrudan kendisi değildir; venom bileşenlerinin yapısal ve farmakolojik özelliklerinden elde edilen bilgiler doğrultusunda tasarlanmış sentetik bir moleküldür (Cushman & Ondetti, 1991). İlacın temel etki mekanizması, anjiyotensin dönüştürücü enzimin (ACE) inhibisyonuna dayanır. ACE aktivitesinin baskılanması, anjiyotensin II oluşumunun azalmasına ve bradikinin yıkımının engellenmesine katkı sağlayarak kan basıncının düşürülmesine yol açmaktadır (Cushman & Ondetti, 1991).

Kaptopril 1981 yılında Amerika Birleşik Devletleri'nde Antihipertansif tedavi amacıyla onaylanmış ve daha sonra farklı kardiyovasküler ve renal endikasyonlarda kullanılmaya başlanmıştır (Freuville et al., 2024).

3.2. Eptifibatid

Eptifibatid, çıngıraklı yılanlardan *Sistrurus miliarius barbouri* venomunda bulunan Barbourin adlı Disintegrinden esinlenilerek geliştirilmiş bir Antitrombosit ilaçtır (Scarborough et al., 1991; Freuville et al., 2024). Barbourin, trombosit yüzeyinde bulunan Glikoprotein IIb/IIIa (GPIIb/IIIa; αIIbβ3) İntegrinine özgül olarak bağlanarak trombosit agregasyonunu engelleyebilen bir venom bileşeni olarak tanımlanmıştır (Scarborough et al., 1991).

Eptifibatid, doğal Barbourinin doğrudan kullanılması yerine, bu molekülün hedef etkileşiminden elde edilen bilgiler doğrultusunda geliştirilmiş sentetik ve siklik bir heptapeptittir (Freuville et al., 2024). İlacın temel etki mekanizması, trombositlerdeki GPIIb/IIIa İntegrinine bağlanarak fibrinojenin trombositler arasında köprü oluşturmasını engellemesine dayanır. Böylece trombositlerin birbirine bağlanması ve agregasyon oluşumu baskılanır (Freuville et al., 2024; Bhatt & Topol, 2000).

Amerika Birleşik Devletleri Gıda ve İlaç Dairesi (FDA) tarafından 1998 yılında onaylanan Eptifibatid, akut koroner sendromların tedavisinde ve perkütan koroner girişim (PCI) sırasında trombotik komplikasyonların önlenmesinde kullanılmıştır (Freuville et al., 2024). Klinik çalışmalarda antitrombosit etkisi gösterilmiş olmakla birlikte, tedavi sırasında dikkat edilmesi gereken başlıca advers etkilerden biri kanama riskindeki artıştır (Bhatt & Topol, 2000).

Eptifibatid, venom bileşenlerinin hedef seçiciliğinden yararlanılarak yeni farmakolojik ajanların geliştirilebileceğini gösteren önemli örneklerden biridir. Barbourinin GPIIb/IIIa İntegrinine yönelik özgül etkileşiminin ortaya konulması, bu hedefe yönelik sentetik bir antitrombosit ajanın geliştirilmesine temel oluşturan araştırma sürecinin önemli bir aşamasını oluşturmuştur (Scarborough et al., 1991; Freuville et al., 2024).

3.3. Tirofiban

Tirofiban, *Echis carinatus* venomunda bulunan Echistatin adlı Disintegrinin GPIIb/IIIa hedeflemesine ilişkin yapısal ve farmakolojik bilgilerden yararlanılarak geliştirilmiş sentetik bir Antitrombosit ilaçtır (Gan et al., 1988; Freuville et al., 2024). Echistatin, trombosit yüzeyindeki GPIIb/IIIa (αIIbβ3) İntegrinine bağlanarak trombosit agregasyonunu güçlü biçimde inhibe eden bir venom bileşeni olarak tanımlanmıştır (Gan et al., 1988).

Doğal venom peptidinin doğrudan kullanılması yerine, disintegrinlerin GPIIb/IIIa integrini ile etkileşiminden elde edilen bilgiler doğrultusunda daha küçük yapılı sentetik bir molekül geliştirilmiştir (Freuville et al., 2024). Tirofiban, trombositlerdeki GPIIb/IIIa integrinine geri dönüşümlü olarak bağlanarak fibrinojenin trombositler arasında köprü oluşturmasını engeller ve böylece trombosit agregasyonunu baskılar (Freuville et al., 2024; Kim et al., 2025).

Tirofiban, 1998 yılında Amerika Birleşik Devletleri Gıda ve İlaç Dairesi (FDA) tarafından akut koroner sendromlarda ve perkütan koroner girişim (PCI) sırasında trombotik komplikasyonların önlenmesine yönelik kullanımı için onaylanmıştır (Kim et al., 2025). İlacın farmakolojik özellikleri arasında hızlı etki başlangıcı ve tedavi sonlandırıldığında antitrombosit etkisinin görece kısa sürede azalması bulunmaktadır (Kim et al., 2025).

Tirofiban, venom disintegrinlerinin hedef moleküllerle etkileşimlerini incelemenin, doğal peptitlerin doğrudan kullanılmasından farklı olarak sentetik ilaç tasarımına da katkı sağlayabileceğini gösteren önemli bir örnektir (Freuville et al., 2024).

3.4. Zikonotid

Zikonotid, denizel koni salyangozu *Conus magus* venomunda bulunan ω-konotoksin MVIIA (ω-MVIIA) peptidinin sentetik eşdeğeridir ve klinik kullanıma giren venom kaynaklı ilaçların önemli örneklerinden birini oluşturmaktadır (Miljanich, 2004; Freuville et al., 2024). Doğal venom bileşeninin biyolojik özelliklerinin ayrıntılı olarak belirlenmesi, bu peptidin terapötik bir ajan olarak geliştirilmesine temel oluşturmuştur (Miljanich, 2004).

Zikonotidin temel etki mekanizması, nöronlarda bulunan N-tipi Voltaj Bağımlı Kalsiyum Kanallarının (CaV2.2) seçici biçimde bloke edilmesine dayanır (Miljanich, 2004).

Bu kanalların inhibisyonu, ağrı iletiminde görev alan nörotransmitterlerin salınımını azaltarak merkezi sinir sistemindeki ağrı sinyallerinin iletimini baskılar (Miljanich, 2004). Zikonotid Opioid reseptörleri üzerinden etki göstermediğinden, Opioidlerden farklı bir analjezik mekanizma sunmaktadır (Freuville et al., 2024).

Amerika Birleşik Devletleri Gıda ve İlaç Dairesi (FDA) tarafından 2004 yılında onaylanan Zikonotid, diğer tedavilere yanıt vermeyen veya diğer tedavilerin tolere edilemediği hastalarda şiddetli kronik ağrının tedavisinde kullanılmaktadır (Miljanich, 2004; Freuville et al., 2024). Peptidin sistemik uygulama sonrasında merkezi sinir sistemine yeterli miktarda ulaşamaması nedeniyle ilaç, intratekal infüzyon yoluyla doğrudan beyin omurilik sıvısına uygulanmaktadır (Miljanich, 2004). Baş dönmesi, bulantı, konfüzyon ve çeşitli nörolojik veya psikiyatrik advers etkiler görülebilmesi nedeniyle tedavi sırasında dikkatli hasta seçimi ve klinik izlem gerekmektedir (Freuville et al., 2024).

Zikonotid, venom peptitlerinin belirli iyon kanallarına yönelik yüksek seçiciliğinin terapötik amaçlarla değerlendirilebileceğini gösteren önemli bir örnektir. Aynı zamanda doğal bir venom peptidinin biyolojik özelliklerinin ayrıntılı biçimde incelenerek klinik kullanıma yönelik sentetik bir ilaca dönüştürülebileceğini ortaya koymaktadır (Miljanich, 2004; Freuville et al., 2024).

3.5. Eksenatid

Eksenatid, Gila canavarı (*Heloderma suspectum*) venomunda bulunan Exendin-4 peptidinin yapısal özelliklerinden yararlanılarak geliştirilen ve tip 2 diyabet tedavisinde kullanılan bir GLP-1 reseptör agonistidir (Eng et al., 1992; Drucker, 2003). Exendin-4'ün GLP-1 ile benzer biyolojik özellikler göstermesi ve daha uzun süreli etki sağlayabilmesi, bu peptidin terapötik bir aday olarak araştırılmasına temel oluşturmuştur (Eng et al., 1992; Drucker, 2003).

Eksenatid, GLP-1 reseptörlerini aktive ederek Glukoza bağımlı İnsülin salınımını artırmakta ve Glukagon salınımını azaltmaktadır. Bunun yanında mide boşalmasını yavaşlatarak ve tokluk sinyallerini destekleyerek kan Glukozunun kontrolüne katkıda bulunmaktadır (Drucker, 2003). Bu etkiler, Eksenatidin tip 2 diyabet tedavisindeki farmakolojik etkilerinin temelini oluşturmaktadır.

Amerika Birleşik Devletleri Gıda ve İlaç Dairesi (FDA) tarafından 2005 yılında onaylanan Eksenatid, tip 2 diyabetli hastalarda glisemik kontrolün sağlanmasına yardımcı olmak amacıyla kullanılmaktadır (Kim et al., 2025). Klinik araştırmalarda Eksenatid tedavisinin kan glukozu ve HbA1c düzeylerinde iyileşme sağlayabildiği gösterilmiştir. Tedavi sırasında özellikle bulantı, kusma ve diğer gastrointestinal yakınmalar görülebilmektedir (Drucker, 2003; Freuville et al., 2024).

Eksenatid, hayvan kaynaklı bir peptidin biyolojik özelliklerinin araştırılarak metabolik hastalıkların tedavisinde kullanılabilen sentetik bir ilaca dönüştürülebileceğini gösteren önemli bir örnektir (Eng et al., 1992; Drucker, 2003).

4. FARKLI HAYVAN VENOMLARININ TERAPÖTİK POTANSİYELİ

4.1. Yılan Venomlarının Terapötik Potansiyeli

Yılan venomları, ilaç geliştirme araştırmalarında en fazla incelenen venom kaynakları arasında yer almakta ve özellikle kardiyovasküler hastalıklar olmak üzere farklı tedavi alanlarında araştırılmaktadır (Freuville et al., 2024). Bu venomlar; enzimler, disintegrinler, fosfolipaz A_2, serin proteazlar ve metalloproteinazlar gibi çok sayıda biyolojik aktif molekül içermektedir (Tasoulis & Isbister, 2017).

Yılan venomlarındaki biyoaktif bileşenlerin hedef moleküllerle etkileşimlerinin incelenmesi, ACE inhibitörleri ve antitrombosit ilaçların geliştirilmesine yönelik önemli araştırmalara temel oluşturmuştur (Freuville et al., 2024). Bazı yılan venom bileşenlerinin kanser hücrelerinin proliferasyonu, anjiyogenez ve hücre göçü gibi süreçleri etkileyebildiği deneysel çalışmalarda araştırılmıştır (Freuville et al., 2024). Ayrıca bazı venom bileşenlerinin antimikrobiyal ve antiinflamatuvar aktiviteleri de araştırılmakta olup, bu moleküller enfeksiyon ve inflamasyonla ilişkili hastalıklar açısından deneysel araştırmalarda değerlendirilmektedir (Kim et al., 2025; Samy et al., 2017).

4.2. Akrep Venomlarının Terapötik Potansiyeli

Akrep venomları, başta Sodyum (Na^+) ve Potasyum (K^+) iyon kanalları olmak üzere çok sayıda iyon kanalını hedefleyen biyolojik aktif peptitler içermektedir (Rodríguez de la Vega & Possani, 2005; Ortiz et al., 2015). Bu hedef özellikleri nedeniyle akrep venom peptitleri; nörolojik, otoimmün ve kanserle

ilişkili hastalıkların araştırılmasında farmakolojik adaylar olarak incelenmektedir (Ortiz et al., 2015; Freuville et al., 2024).
Özellikle Klorotoksin gibi bazı akrep venom peptitlerinin glioma hücrelerini seçici olarak hedefleyebildiği ve bu özelliklerinin tümör görüntüleme ile hedefe yönelik tedavi yaklaşımlarında araştırıldığı bildirilmektedir (Soroceanu et al., 1998; Cohen et al., 2018). Ayrıca bazı akrep toksinlerinin immün hücrelerde bulunan Potasyum kanallarını modüle edebilmesi, bu moleküllerin inflamatuvar ve otoimmün hastalıkların tedavisine yönelik araştırmalarda değerlendirilmesine olanak sağlamaktadır (Rodríguez de la Vega & Possani, 2005; Freuville et al., 2024).

4.3. Örümcek Venomlarının Terapötik Potansiyeli
Örümcek venomları, sinir sistemi üzerinde etkili çok sayıda peptit toksin içermekte ve bu moleküller özellikle Voltaj Bağımlı Sodyum, Potasyum Ve Kalsiyum Kanalları gibi iyon kanallarını hedefleyebilmektedir (Saez et al., 2010; King, 2011). Bu hedefler nedeniyle örümcek venom peptitleri, özellikle kronik ağrı ve diğer nörolojik hastalıklarla ilişkili mekanizmaların araştırılmasında ve yeni ilaç adaylarının geliştirilmesinde incelenmektedir (King, 2011; Saez et al., 2010).
Deneysel çalışmalar, bazı örümcek venom peptitlerinin ağrı iletiminde görev alan iyon kanallarını modüle ederek analjezik etkiler gösterebildiğini ortaya koymuştur (King, 2011; Saez et al., 2010). Ayrıca bazı venom peptitlerinin nöroprotektif, antikanser ve antimikrobiyal aktiviteleri de araştırılmakta; bu moleküller farklı hastalık alanlarında terapötik adaylar olarak değerlendirilmektedir (Saez et al., 2010; Kim et al., 2025).

4.4. Koni Salyangozu Venomlarının Terapötik Potansiyeli
Koni salyangozu (*Conus* spp.) venomları, sinir sistemi üzerinde etkili çok sayıda Konotoksin içeren zengin doğal kaynaklardır (Terlau & Olivera, 2004; Robinson & Norton, 2014). Bu peptitler; Voltaj Bağımlı Kalsiyum, Sodyum Ve Potasyum Kanalları ile Nikotinik Asetilkolin Reseptörleri gibi birçok moleküler hedefi seçici biçimde modüle edebilmektedir (Terlau & Olivera, 2004).
Konotoksinlerin iyon kanalları ve reseptörler üzerindeki özgül etkileri, özellikle kronik ağrı ve diğer nörolojik hastalıklarla ilişkili araştırmalarda bu moleküllere olan ilgiyi artırmıştır (Terlau & Olivera, 2004; Freuville et al., 2024). Ayrıca farklı konotoksin ailelerinin farmakolojik özellikleri, yeni nöroaktif ilaç adaylarının geliştirilmesi açısından araştırılmaktadır (Kim et al., 2025).

4.5. Arı Venomunun Terapötik Potansiyeli
Arı venomunun temel bileşenleri arasında Melittin, Apamin, Adolapin ve Fosfolipaz A_2 gibi biyolojik aktif moleküller yer almakta olup, bu bileşenler çeşitli farmakolojik etkilere sahiptir (Son et al., 2007; Wehbe et al., 2019). Özellikle Melittin, hücre membranlarıyla etkileşebilmesi ve çeşitli biyolojik aktiviteler göstermesi nedeniyle arı venomunun terapötik açıdan en fazla ilgi gören bileşenlerinden biridir (Wehbe et al., 2019).
Deneysel çalışmalar, arı venomunda bulunan bazı moleküllerin antikanser, antimikrobiyal, antiinflamatuvar ve immünomodülatör aktiviteler gösterebildiğini ortaya koymuştur (Wehbe et al., 2019; Freuville et al., 2024).
Arı venom peptitlerinin hedef seçiciliğinin artırılması ve toksik etkilerinin azaltılmasına yönelik biyoteknolojik yaklaşımlar araştırılmaktadır (Freuville et al., 2024). Bu yaklaşımlar, arı venom bileşenlerinin farklı hastalık alanlarında terapötik adaylar olarak değerlendirilmesine yönelik araştırmaları desteklemektedir (Kim et al., 2025).

5. Venom Kökenli Moleküllerin Hastalıklardaki Terapötik Potansiyeli
5.1. Kanser
Hayvan venomlarında bulunan bazı peptit ve proteinler, tümör hücrelerini hedefleme özellikleri nedeniyle kanser araştırmalarında dikkat çekmektedir (Cohen et al., 2018; Soroceanu et al., 1998).

5.2. Kronik Ağrı ve Nörolojik Hastalıklar
Hayvan venomlarında bulunan bazı peptitler, iyon kanalları ve reseptörler üzerindeki etkileri nedeniyle kronik ağrı ve nörolojik hastalıklarla ilişkili farmakolojik araştırmalarda incelenmektedir (King, 2011; Freuville et al., 2024).

Özellikle koni salyangozu venomlarında bulunan Konotoksinler, voltaj bağımlı kalsiyum kanalları başta olmak üzere sinir iletiminde görev alan çeşitli moleküler hedefleri etkileyebilmektedir (Terlau & Olivera, 2004). Örümcek venom peptitleri ise sodyum, potasyum ve kalsiyum kanalları gibi iyon kanallarını hedefleyebilmeleri nedeniyle ağrı mekanizmaları ve nörolojik süreçlerin araştırılmasında incelenmektedir (King, 2011; Saez et al., 2010).

5.3. Enfeksiyon Hastalıkları

Antimikrobiyal direnç, küresel ölçekte önemli bir halk sağlığı sorunu oluşturmakta ve yeni antimikrobiyal ajanların geliştirilmesini gerekli kılmaktadır (Antimicrobial Resistance Collaborators, 2022). Hayvan venomlarında bulunan bazı peptitler, bakteriler ve mantarlar başta olmak üzere çeşitli mikroorganizmalar üzerindeki biyolojik etkileri nedeniyle antimikrobiyal araştırmalarda incelenmektedir (Samy et al., 2017; Kim et al., 2025).

Yılan, arı, akrep ve örümcek venomlarında bulunan bazı peptitlerin mikroorganizmaların hücre zarını etkileyerek veya hücresel süreçleri bozarak antimikrobiyal aktivite gösterebildiği deneysel çalışmalarda ortaya konmuştur (Samy et al., 2017; Wehbe et al., 2019). Ayrıca bazı venom bileşenlerinin biyofilm oluşumunu baskılayabildiği ve mevcut antimikrobiyal ajanlarla kombinasyonlarının deneysel olarak araştırıldığı bildirilmektedir (Samy et al., 2017; Kim et al., 2025).

Heterometrus petersi akrebi venomundan türetilen HP1090 daha önce membran aktif bir antiviral bileşik olarak tanımlanan kısa, katyonik ve amfipatik bir peptit kimyasal olarak sentezlenerek, Herpes Simpleks Virüs tip 1 ve 2 (HSV-1, HSV-2), İnsan İmmün Yetmezlik Virüsü tip 1 (HIV-1) ve Zika virüsü (ZIKV) dahil olmak üzere çeşitli zarflı virüslere karşı doza bağımlı virüsidal aktivite sergilediği gösterilmiştir. İncelemeler sonucunda HP1090'ı membran aktif bir zehir peptidi olarak değerlendirilmiştir (Asuzano et al., 2026).

5.4. İnflamatuvar ve Otoimmün Hastalıklar

Kronik inflamatuvar ve otoimmün hastalıklar, bağışıklık sisteminin düzensiz aktivasyonu sonucu gelişen ve uzun süreli tedavi gerektiren hastalık grupları arasında yer almaktadır (Schett et al., 2021). Hayvan venomlarında bulunan bazı peptit ve proteinler, immün yanıt ve inflamatuvar süreçler üzerindeki etkileri nedeniyle inflamatuvar ve otoimmün hastalıklarla ilişkili araştırmalarda incelenmektedir (Freuville et al., 2024; Kim et al., 2025).

Deneysel çalışmalar, özellikle arı venomunda bulunan bazı bileşenlerin proinflamatuvar yanıtları ve immün hücrelerin aktivitesini etkileyebildiğini göstermektedir (Son et al., 2007; Kim et al., 2025). Bu bulgular doğrultusunda, venom bileşenlerinin inflamatuvar ve otoimmün hastalıklarla ilişkili moleküler süreçlerdeki etkileri araştırılmaktadır (Freuville et al., 2024; Kim et al., 2025).

5.5. Metabolik Hastalıklar

Tip 2 diyabet başta olmak üzere metabolik hastalıklar, dünya genelinde önemli halk sağlığı sorunları arasında yer almaktadır (Sun et al., 2022). Hayvan venomlarında bulunan bazı peptitler, özellikle metabolik süreçlerde rol alan reseptörleri ve sinyal yollarını etkileyebilmeleri nedeniyle metabolik hastalıklar açısından araştırılmaktadır (Freuville et al., 2024; Kim et al., 2025).

Bu alandaki en belirgin örneklerden biri, *Heloderma suspectum* venomunda bulunan Exendin-4'ün GLP-1 reseptör agonisti olarak araştırılması ve daha sonra sentetik bir ilaç olan Eksenatidin geliştirilmesine temel oluşturmasıdır (Eng et al., 1992; Drucker, 2003).

5.6. Kardiyovasküler Hastalıklar

Hayvan venomlarında bulunan bazı biyolojik aktif moleküller, kan basıncı, trombosit agregasyonu ve hemostatik süreçler üzerindeki etkileri nedeniyle kardiyovasküler farmakoloji alanında araştırılmaktadır (Freuville et al., 2024).

Yılan venomlarında bulunan bazı bileşenlerin ACE ve trombosit integrinleri gibi hedeflerle etkileşiminin araştırılması, antihipertansif ve antitrombosit ilaçların geliştirilmesine temel oluşturan önemli bulgular sağlamıştır (Ferreira et al., 1970; Cushman & Ondetti, 1991; Scarborough et al., 1991; Freuville et al., 2024). Bunun yanında, farklı venom bileşenlerinin tromboz ve diğer kardiyovasküler süreçlerle ilişkili moleküler mekanizmalar üzerindeki etkileri de araştırılmaktadır (Freuville et al., 2024; Kim et al., 2025).

6. Venom Kökenli İlaç Geliştirmede Sınırlılıklar Ve Gelecek Perspektifi

6.1. Toksisite ve Güvenlik Sorunları

Hayvan venomlarında bulunan biyolojik aktif moleküllerin terapötik amaçlarla değerlendirilmesinde toksisite ve güvenlilik önemli sınırlılıklar oluşturmaktadır (Freuville et al., 2024). Venom bileşenlerinin hedef dışı dokular üzerindeki istenmeyen etkileri, terapötik dozun belirlenmesini ve güvenli bir doz aralığının oluşturulmasını güçleştirebilmektedir (King, 2011; Freuville et al., 2024). Bu nedenle preklinik toksisite değerlendirmeleri, doz optimizasyonu ve uzun dönem güvenlilik çalışmalarının yürütülmesi, venom kaynaklı ilaç adaylarının geliştirilmesinde önemli aşamaları oluşturmaktadır (Kim et al., 2025; Muttenthaler et al., 2021).

6.2. Biyoyararlanım ve Farmakokinetik Sınırlılık

Venom kökenli peptit ve proteinlerin klinik kullanıma aktarılmasındaki önemli engellerden biri, düşük biyoyararlanım ve elverişsiz farmakokinetik özellikleridir (Freuville et al., 2024; Muttenthaler et al., 2021). Peptit ve protein yapısındaki adaylarda oral emilim sınırlı olabilmekte, kısa plazma yarı ömrü ve proteolitik yıkım ise sistemik maruziyeti azaltabilmektedir (Muttenthaler et al., 2021). Bu sınırlılıkların aşılması amacıyla uygun uygulama yolları, ilaç taşıma sistemleri ve moleküler optimizasyon yaklaşımları araştırılmaktadır (Freuville et al., 2024; Kim et al., 2025).

6.3. Stabilite ve Proteolitik Parçalanma

Peptit yapısındaki venom bileşenlerinin terapötik kullanımında karşılaşılan sorunlardan biri, fizyolojik ortamda yapısal ve kimyasal stabilitelerinin yeterli düzeyde korunamamasıdır (Freuville et al., 2024; Muttenthaler et al., 2021). Stabilitenin yetersiz olması, moleküllerin biyolojik bütünlüğünü ve hedef bölgeye ulaşan etkin molekül miktarını sınırlayabilmektedir (Muttenthaler et al., 2021). Bu nedenle peptitlerin yapısal olarak optimize edilmesi ve uygun formülasyon veya taşıma sistemleriyle korunması, stabilite sorunlarının azaltılmasına yönelik başlıca yaklaşımlar arasında yer almaktadır (Freuville et al., 2024; Kim et al., 2025).

6.4. Hedefe Özgüllük ve Hedef Dışı Etkiler

Venom kaynaklı biyolojik aktif moleküllerde hedef seçiciliği terapötik açıdan önemli bir özellik olmakla birlikte, bazı adayların hedef dışı reseptör veya dokularla etkileşebilmesi ilaç geliştirme sürecinde önemli bir sınırlılık oluşturabilmektedir (Freuville et al., 2024). Hedef dışı etkileşimler, istenmeyen biyolojik etkilerin ortaya çıkması ve güvenlilik profilinin olumsuz etkilenmesiyle sonuçlanabilmektedir (Muttenthaler et al., 2021). Bu nedenle aday moleküllerin hedef seçiciliğinin artırılmasına yönelik yapısal optimizasyon ve hedefli taşıma yaklaşımları araştırılmaktadır (Freuville et al., 2024; Kim et al., 2025).

6.5. Üretim Maliyetleri ve Endüstriyel Ölçeklendirme

Venom kökenli moleküllerin klinik kullanıma kazandırılmasında karşılaşılan önemli zorluklardan biri, üretim süreçlerinin karmaşık ve maliyetli olmasıdır (Freuville et al., 2024; Muttenthaler et al., 2021). Doğal venom kaynaklarından yeterli miktarda aktif bileşenin elde edilmesindeki güçlükler ve saflaştırma gereksinimleri, üretimin endüstriyel ölçekte gerçekleştirilmesini zorlaştırabilmektedir (Freuville et al., 2024; Muttenthaler et al., 2021). Bu sınırlılıkların aşılması amacıyla rekombinant protein üretimi, sentetik peptit üretimi ve farklı biyoteknolojik üretim yaklaşımları araştırılmakta; bu yöntemlerin ölçeklenebilir üretim açısından sağlayabileceği avantajlar değerlendirilmektedir (Freuville et al., 2024; Kim et al., 2025).

6.6. Klinik Çalışmalar ve Düzenleyici Süreçler

Klinik geliştirme aşamasına ulaşan venom kökenli adayların etkinlik ve güvenlilik profillerinin değerlendirilmesi için uygun fazlardaki klinik çalışmaların yürütülmesi gerekmektedir (Freuville et al., 2024). Klinik geliştirme sürecinde güvenlilik, etkinlik, kalite ve düzenleyici gerekliliklerin karşılanması, adayların klinik kullanıma ulaşmasında temel aşamaları oluşturmaktadır (Freuville et al., 2024).

6.7. Peptit Mühendisliği ve Moleküler Optimizasyon

Peptit mühendisliği, venom kökenli peptitlerin farmakolojik özelliklerinin geliştirilmesine yönelik önemli yaklaşımlardan biridir (Muttenthaler et al., 2021).

Bu yaklaşım kapsamında amino asit dizileri ve moleküler yapı üzerinde yapılan değişikliklerle aday peptitlerin farmakolojik özelliklerinin geliştirilmesi amaçlanmaktadır (Muttenthaler et al., 2021). Bu tür yapısal optimizasyonlar, venom kökenli peptitlerin ilaç adayı olarak değerlendirilmesinde farmakolojik özelliklerin iyileştirilmesine yönelik bir yaklaşım sunmaktadır (Freuville et al., 2024; Kim et al., 2025).

6.8. Gelecek Perspektifleri

Hayvan venomları, zengin moleküler çeşitlilikleri ve farklı biyolojik hedeflerle etkileşebilen bileşenleri nedeniyle yeni ilaç adaylarının araştırılmasında dikkat çeken doğal kaynaklar arasında yer almaktadır (Freuville et al., 2024). Peptit mühendisliği, rekombinant üretim ve gelişmiş ilaç taşıma sistemlerindeki ilerlemelerin, venom kökenli adayların farmakolojik özelliklerinin geliştirilmesine katkı sağlayabileceği düşünülmektedir (Muttenthaler et al., 2021; Kim et al., 2025). Multidisipliner araştırmaların ve temel bilimler ile klinik araştırmalar arasındaki etkileşimin güçlendirilmesi, venom kökenli adayların terapötik açıdan değerlendirilmesine katkı sağlayabilecek yaklaşımlar arasında görülmektedir (Freuville et al., 2024).

SONUÇ

Hayvan venomları, içerdikleri peptitler, proteinler ve diğer biyolojik aktif moleküller sayesinde modern ilaç keşfi ve geliştirme çalışmalarında önemli doğal kaynaklar arasında yer almaktadır (Freuville et al., 2024). İncelenen çalışmalar, venom bileşenlerinin farklı moleküler hedefler üzerinden etkili olabildiğini ve bu özelliklerin bazı moleküllerin ilaç geliştirme süreçlerine aktarılmasına temel oluşturduğunu göstermektedir (Freuville et al., 2024; Kim et al., 2025).

Venom kökenli moleküller kardiyovasküler hastalıklar ve kronik ağrı gibi bazı alanlarda klinik kullanıma ulaşmış örneklere sahipken, kanser, enfeksiyon, inflamasyon ve metabolik hastalıklar gibi alanlardaki birçok aday hâlen klinik öncesi veya araştırma aşamasındadır (Freuville et al., 2024; Kim et al., 2025).

Biyoteknoloji, peptit mühendisliği ve rekombinant üretim alanlarındaki gelişmeler, venom kökenli adayların yapısal ve farmakolojik özelliklerinin geliştirilmesi açısından önemli araştırma olanakları sunmaktadır (Muttenthaler et al., 2021; Kim et al., 2025). Bu nedenle venom kaynaklı moleküllerin terapötik aday olarak değerlendirilmesinde disiplinler arası araştırmaların sürdürülmesi ve klinik kanıt düzeyinin güçlendirilmesi önem taşımaktadır.

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GENÇ ERİŞKİNLERDE SİTOKİN PROFİLİ: İNFLAMATUVAR VE ANTİ-ENFLAMATUVAR DENGEYE YÖNELİK REFERANS ARALIKLARININ BELİRLENMESİ

CYTOKINE PROFILING IN YOUNG ADULTS: DETERMINING REFERENCE RANGES FOR INFLAMMATORY AND ANTI-INFLAMMATORY BALANCE

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ÖZET
Bağışıklık sisteminin temel düzenleyicileri olan sitokinler, fizyolojik ve patolojik süreçlerde inflamatuvar ile anti-inflamatuvar dengeyi sağlamada kritik bir rol oynamaktadır. İnsan ömrünün fizyolojik değişim ve hücresel adaptasyon açısından en dinamik evrelerinden biri olan genç erişkinlik dönemi (18-30 yaş), bağışıklık yanıtının hücresel düzeyde optimize edildiği bir süreçtir. Bu araştırmanın temel amacı, sağlıklı genç erişkin bireylerde pro-inflamatuvar ve anti-inflamatuvar sitokin düzeylerini ölçerek bu yaş grubuna özgü klinik referans aralıklarını belirlemek ve immünolojik denge profilini ortaya koymaktır. Araştırmaya, yaş ortalaması 20.9 ± 2.5 olan toplam 80 sağlıklı gönüllü (58 kadın, 22 erkek) dahil edilmiştir. Çalışma kapsamında katılımcıların demografik özellikleri, medikal öyküleri ve yaşam tarzı faktörleri standardize edilmiş anketler aracılığıyla değerlendirilmiş; sitokin profillemesi için her katılımcıdan 5 cc venöz kan örneği alınarak laboratuvar analizleri gerçekleştirilmiştir. Elde edilen bulgular incelendiğinde, hücresel bağışıklığı baskılayıcı etki gösteren anti-enflamatuvar sitokinlerden IL-4 konsantrasyonu ortalama 1416.8, TGF-β1 160.1 ve IL-10 ise 3.1 düzeyinde tespit edilmiştir. İmmün yanıtı uyarıcı enflamatuvar sitokin profiline bakıldığında ise TNF-α ortalaması 57.4, IFN-γ 64.5, IL-12 94.4 ve IL-1β konsantrasyonu 0.06 olarak saptanmıştır. Genç erişkinlerde inflamatuvar ve anti-inflamatuvarmedyatörlerin bu denge durumu, sağlıklı immünolojik profilin anlaşılması açısından büyük önem taşımaktadır. Sonuç olarak, belirlenen bu referans aralıkları, genç erişkinlerde sağlıklı immün durumun klinik sınırlarını tanımlamakta ve yaşlanma, otoimmün hastalıklar, kronik stres veya enfeksiyon gibi homeostazı bozan patolojik süreçlerin erken dönemde tespit edilmesinde klinisyenlere kılavuzluk edecek önemli bir fizyolojik zemin oluşturmaktadır.
Anahtar Kelimeler: Sitokin, genç erişkin, inflamasyon, referans aralığı, hücresel bağışıklık.

ABSTRACT
Cytokines, the fundamental regulators of the immune system, play a critical role in maintaining the inflammatory and anti-inflammatory balance in both physiological and pathological processes. Young adulthood (18-30 years), one of the most dynamicphases of human life in terms of physiological change and cellular adaptation, is a period where the immuneresponse is optimized at the cellular level. The primary aim of this research is tomeasurepro-inflammatoryand anti-inflammatory cytokinelevels in healthy young adultstodeterminespecificclinical reference intervalsandrevealtheimmunologicalbalance profile forthisagegroup. A total of 80 healthyvolunteers (58 females, 22 males) with a meanage of 20.9 ± 2.5 yearswereincluded in thestudy. Participants' demographiccharacteristics, medicalhistories, and lifestyle factors were evaluated through standardized questionnaires; forcytokineprofiling, 5 cc venous blood samples were collected from each participant for laboratoryanalysis.

Analysis of the finding srevealed that among the anti-inflammatory cytokine sex hibiting immunosuppressive effects, the mean concentration of IL-4 was 1416.8, TGF-β1 was 160.1, and IL-10 was 3.1. Whenexaminingtheimmune-stimulatinginflammatorycytokine profile, themeanlevel of TNF-α wasdetermined as 57.4, IFN-γ as 64.5, IL-12 as 94.4, and IL-1β concentration as 0.06. This state of balance between inflammatory and anti-inflammatory mediators in young adults is of great importance for understanding the healthy immunological profile. Inconclusion, these established reference intervals define the clinical boundaries of a healthy immunestate in young adults and constitute a crucial physiological baseline that will guide clinicians in the early detection of pathological processes disrupting homeostasis, such as aging, autoimmune diseases, chronic stress, or infections.
Keywords: Cytokine, young adult, inflammation, reference interval, cellularimmunity.

ŞEKİ VE AMASYA ÖRNEĞİNDE TARİHİ TURİZM KENTLERİNDE DİJİTAL KARTOGRAFİK TEMSİLİN KARŞILAŞTIRMALI COĞRAFİ ANALİZİ

A COMPARATIVE GEOGRAPHICAL ANALYSIS OF DIGITAL CARTOGRAPHIC REPRESENTATION IN THE HISTORIC TOURISM CITIES OF SHEKI AND AMASYA

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ÖZET
Turizm mekânı günümüzde yalnızca fiziki çevrede değil, aynı zamanda dijital çevrede de üretilmektedir. Ziyaretçinin rota kararı çoğu zaman destinasyona varmadan önce, çevrimiçi harita platformlarının sunduğu bilgiye dayanarak oluşmaktadır. Bu durum, turizm coğrafyası ile siber coğrafyanın kesişiminde yeni bir araştırma alanı yaratmaktadır: bir destinasyonun fiziki turizm potansiyeli ile bu potansiyelin dijital mekândaki temsili arasındaki uyum ya da uyumsuzluk sorunu. Bu çalışmanın amacı, tarihî turizm kentlerinde dijital kartografik temsilin coğrafi özelliklerini belirlemek ve yapısal olarak benzer iki destinasyon arasında karşılaştırmalı bir analiz yapmaktır. Araştırma alanı olarak Azerbaycan'ın Şeki ve Türkiye'nin Amasya kentleri seçilmiştir. Her iki kent de dağlık rölyef içinde akarsu vadisi boyunca gelişmiş, tarihî ticaret yolları üzerinde yer alan, turizmi geleneksel konut mimarisi, el sanatları ve gastronomi üzerine kurulu orta ölçekli merkezlerdir. Bu yapısal benzerlik, karşılaştırmayı rastlantısal değil coğrafi olarak temellendirilmiş kılmaktadır. Çalışmada gönüllü coğrafi bilgi (VGI) yaklaşımı kullanılmış; açık harita platformlarındaki turizm nesneleri mekânsal yoğunluk, öznitelik bütünlüğü, içerik zenginliği ve güncellenme sıklığı göstergeleri üzerinden karşılaştırılmıştır. Nesnelerin kent içi dağılımı merkez-çeper modeli çerçevesinde değerlendirilmiş, dijital temsilin tarihî çekirdekten uzaklaştıkça nasıl zayıfladığı incelenmiştir. Bulgular, dijital görünürlüğün destinasyonun gerçek turizm potansiyelini tam olarak yansıtmadığını ve mekânsal açıdan dengesiz dağıldığını göstermektedir. Sonuçlar, bölgesel turizm planlamasında dijital altyapının coğrafi boyutunun dikkate alınmasının gerekliliğini ortaya koymaktadır.
Anahtar Kelimeler: Siber coğrafya, turizm coğrafyası, dijital kartografya, gönüllü coğrafi bilgi, Şeki, Amasya.

ABSTRACT
Tourism space today is produced not only in the physical environment but simultaneously in the digital one. Visitors increasingly form their route decisions before arrival, on the basis of information supplied by online mapping platforms. This creates a research field at the intersection of tourism geography and cybergeography: the correspondence, or mismatch, between the physical tourism potential of a destination and its representation in digital space. The aim of this study is to identify the geographical characteristics of digital cartographic representation in historic tourism cities and to conduct a comparative analysis between two structurally similar destinations. Sheki in Azerbaijan and Amasya in Türkiye were selected as study areas. Both are medium-sized centres formed along river valleys within mountainous relief, situated on historic trade routes, and both base their tourism on vernacular house architecture, handicrafts and gastronomy. This structural similarity makes the comparison geographically grounded rather than arbitrary. The study applies a volunteered geographic information (VGI) approach, comparing tourism-related features on open mapping platforms according to spatial density, attribute completeness, content richness and update frequency. The intra-urban distribution of features is assessed within a core-periphery framework, examining how digital representation weakens with increasing distance from the historic core. The findings indicate that digital visibility does not fully reflect the actual tourism potential of a destination and is distributed unevenly in spatial terms. The results underline the necessity of incorporating the geographical dimension of digital infrastructure into regional tourism planning.
Keywords: Cybergeography, tourism geography, digital cartography, volunteered geographic information, Sheki, Amasya.

STUDY OF THE STRUCTURE, ELECTRICAL AND OPTICAL PROPERTIES OF THERMAL EVAPORATION-SYNTHESIZED CdSe;0.5%Ho NANOCRYSTAL

TERMIK BUXARLANMA YOLU ILƏ SİNTEZ EDİLMİŞ CDSE;0.5%HO NANOKRİSTALININ QURULUŞU , ELEKTRİK VƏ OPTİK XASSƏLƏRİNİN

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XÜLASƏ
Bu tədqiqatda, soyuq şüşə substratlarına ənənəvi istilik buxarlanma texnikası ilə dondurulmamış və İçinə dondurulmuş CdSe;0.5%Ho -nin yarımkeçirici nazik təbəqələri yerləşdirilib. Termal buxarlanma texnikasından istifadə edərək, otaq temperaturunda şüşə substratlarına lehimlənməmiş və 1% In lehimlənmiş CdSe;0.5%Ho nazik təbəqələri çökdürülmüşdür. SEM mikroqrafından kristal dənəciklərin stexiometrik və homogen əmələ gəlmələri müşahidə edilmişdi. Nazik təbəqələrin struktur və elektrik xüsusiyyətləri XRD, SEM, temperaturdan asılı elektrik keçiriciliyi və Hall Effekti ölçmələri vasitəsilə araşdırılıb. Rentgen difraksiyası (XRD) analizi (002) istiqamətində üstünlük təşkil edən istiqamət göstərib. XRD və SEM ölçmələri 26-dan 29 nm-ə qədər artmasına səbəb olub. Keçiricilik ölçmələri göstərib ki, soyuq şüşə altlıqda yerləşdirilmişhesabina keçiriciliyin təxminən dörd böyüklük dərəcəsinə artmasına səbəb olur. Bu nazik təbəqələrin zolaq boşluğu haqqında məlumat fotocərəyan və udma ölçmələrinin spektral paylanması vasitəsilə araşdırılmışdır. Zolaq boşluğu enerjiləri fotokeçiricilik ölçmələrindən hesablanmış və udma spektrlərindən çıxarılan nəticələrlə müqayisə edilmişdir.
Açar sözlər: CdSe; Nazik təbəqələr; Termal buxarlanma; Dopinq; Elektrik xüsusiyyətləri

ABSTRACT
In this study, semiconductor thin films of unannealed and unannealed CdSe;0.5%Ho were deposited on cold glass substrates by conventional thermal evaporation technique. Unannealed and 1% Inannealed CdSe;0.5%Ho thin films were deposited on glass substrates at room temperature using thermal evaporation technique. The SEM micrographs showed stoichiometric and homogeneous formation of crystal grains. The structural and electrical properties of the thin films were investigated by XRD, SEM, temperature-dependent electrical conductivity and Hall Effect measurements. X-ray diffraction (XRD) analysis showed a dominant orientation in the (002) direction. XRD and SEM measurements showed an increase in the conductivity from 26 to 29 nm. Conductivity measurements showed that the conductivity increased by about four orders of magnitude when placed on a cold glass substrate. The band gap information of these thin films was investigated by spectral distribution of photocurrent and absorption measurements. The band gap energies were calculated from the photoconductivity measurements and compared with the results deduced from the absorption spectra.
Keywords: CdSe; Thin films; Thermal evaporation; Doping; Electrical properties

”ALGORİTMALARIN GÖNLÜNÜ HOŞ ETMEYE ÇALIŞIYORUZ”: MEDYA EMEĞİNDE ALGORİTMİK YÖNETİMİN SONUÇLARI[44]

”WE'RE TRYING TO PLEASE THE ALGORITHMS”: THE CONSEQUENCES OF ALGORITHMIC MANAGEMENT IN MEDIA LABOUR[45]

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ÖZET
Dijitalleşmeyle birlikte algoritmik yönetim, medya sektöründe içerik üretiminden performans değerlendirmesine, görünürlükten iş organizasyonuna kadar birçok süreci şekillendiren temel yönetim mekanizmalarından biri hâline gelmiştir. Bu dönüşüm, medya emekçilerinin çalışma deneyimlerini yeniden yapılandırırken kontrol, motivasyon, özerklik, adalet algısı, performans, stres ve örgütsel bağlılık gibi birçok bireysel ve örgütsel çıktıyı da etkilemektedir. Bu çalışma, medya emeği bağlamında algoritmik yönetimin çalışanlar tarafından nasıl deneyimlendiğini ve bu deneyimlerin iş yaşamına yansıyan sonuçlarını ortaya koymayı amaçlamaktadır.
Araştırma nitel araştırma deseniyle yürütülmüştür. Veriler, Türkiye’deki farklı medya kuruluşlarında çalışan 16 medya emekçisiyle gerçekleştirilen yarı yapılandırılmış mülakatlar yoluyla toplanmış ve tematik analiz yöntemiyle çözümlenmiştir. Analiz sonucunda algoritmik yönetimin medya emeği üzerindeki etkilerini ortaya koyan çeşitli temalar belirlenmiştir.
Bulgular, algoritmik yönetimin medya emeğinde çift yönlü bir etki oluşturduğunu göstermektedir. Bir yandan performansın ölçülebilirliğini artırması, iş süreçlerini hızlandırması ve üretim hedeflerini görünür kılması gibi işlevsel katkılar sağlarken, diğer yandan sürekli görünür olma baskısı, algoritmalara uyum sağlama çabası, stres düzeyinde artış, özerklik kaybı, adalet algısının zedelenmesi ve motivasyon ile örgütsel bağlılık üzerindeki değişim gibi önemli bireysel ve örgütsel çıktılara yol açmaktadır. Katılımcıların sıklıkla dile getirdiği "algoritmaların gönlünü hoş etmeye çalışıyoruz" ifadesi, algoritmik sistemlerin yalnızca teknik araçlar değil, çalışan davranışlarını yönlendiren yeni yönetim mekanizmaları olarak algılandığını ortaya koymaktadır.
Bu çalışmanın algoritmik yönetimin medya emeği üzerindeki etkilerini iletişim çalışmaları ile örgütsel davranış literatürünü bir araya getiren disiplinlerarası bir perspektifle ele alarak literatüre katkı sunması beklenmektedir.
Anahtar Kelimeler: Algoritmik Yönetim, Dijital Emek, Örgütsel Davranış, Medya Emeği, Tematik Analiz.

ABSTRACT
With digitalization, algorithmic management has become one of the fundamental management mechanisms shaping various processes in the media sector, including content production, performance evaluation, visibility, and work organization. While this transformation restructures the work experiences of media workers, it also affects various individual and organizational outcomes such as control, motivation, autonomy, perceptions of justice, performance, stress, and organizational commitment. This study aims to reveal how algorithmic management is experienced by employees within the context of media labor and to examine the implications of these experiences for working life.

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The research was conducted using a qualitative research design. Data were collected through semi-structured interviews with 16 media workers employed in different media organizations in Türkiye and analyzed using thematic analysis. The analysis identified several themes that reveal the effects of algorithmic management on media labor.

The findings demonstrate that algorithmic management forms a dual impact on media labor. On the one hand, it provides functional contributions by increasing the measurability of performance, accelerating work processes, and making production targets more visible. On the other hand, it leads to significant individual and organizational outcomes, including constant pressure to remain visible, efforts to adapt to algorithms, increased stress levels, loss of autonomy, weakened perceptions of justice, and changes in motivation and organizational commitment. The frequently expressed statement by participants, "we are trying to please the algorithms," indicates that algorithmic systems are perceived not merely as technical tools but as new management mechanisms that guide employee behaviors.

This study is expected to contribute to the literature by examining the effects of algorithmic management on media labor through an interdisciplinary perspective that brings together communication studies and organizational behavior literature.

Keywords: Algorithmic Management, Digital Labor, Organizational Behavior, Media Labor, Thematic Analysis.

İLHAN BERK'İN TAYMİS ŞİİRİNE ÇEVRESEL BEŞERİ BİLİMLER ÇERÇEVESİNDEN BİR OKUMA MODELİ

A READING MODEL OF ILHAN BERK'S POEM TAYMIS FROM THE PERSPECTIVE OF ENVIRONMENTAL HUMANITIES

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ÖZET
İlhan Berk'in Taymis şiiri, nehir ile insan, tarih, kent ve kültür arasındaki ilişkilerin iç içe geçtiği çok katmanlı bir yapı ortaya koymaktadır. Bu çalışmada şiir, çevresel beşeri bilimler perspektifinden ele alınmaktadır. Çevre, insan yaşamından bağımsız bir alan olarak değerlendirilmemekte; tarih, kültür, kent, ekonomi ve siyasetle kurduğu ilişkiler üzerinden incelenmektedir. Bu doğrultuda ekokritik yaklaşımın yanı sıra ekolojik özneleşme, ekolojik hafıza, kentsel ekoloji, tarihsel ekoloji ve politik ekoloji kavramlarından yararlanılmaktadır. Temel yaklaşım, Taymis'in şiirde yalnızca bir mekân veya doğal unsur olarak kullanılmadığı düşüncesine dayanmaktadır. Nehir, şiir boyunca hareket eden, farklı mekânlarla ilişki kuran ve tarihsel süreçleri taşıyan çevresel bir aktör olarak kurulmaktadır.
Şiir, beş aşamalı bir okuma modeli üzerinden incelenmektedir. İlk aşamada Taymis'in insan dışı bir varlık olarak özneleşmesi şeklinde incelenir. İkinci aşamada nehir, tarih ve bellek arasındaki ilişki değerlendirilmektedir. Üçüncü aşamada Taymis ile Londra arasındaki kentsel ve çevresel ilişki incelenmektedir. Dördüncü aşamada farklı tarihsel dönemlerin nehir çevresinde bir araya gelmesi tarihsel ekoloji bağlamında ele alınmaktadır. Beşinci aşamada ise Taymis'in ticaret, kölelik, emek, ulaşım ve emperyalizmle ilişkisi politik ekoloji çerçevesinde değerlendirilmektedir.
Sonuç olarak elde edilen bulgular, Taymis'in şiirde çok katmanlı bir çevresel aktör olarak kurulduğunu göstermektedir. Nehir, Londra'nın tarihini ve kentsel yaşamını taşımakta, farklı coğrafyaları birbirine bağlamaktadır. Böylece Taymis, doğal çevre ile insan tarihi arasındaki karşılıklı ilişkiyi görünür kılan ve çevreyi tarihsel, kültürel, kentsel ve politik boyutlarıyla ele alan ekolojik bir şiir olarak değerlendirilmektedir.
Anahtar Kelimeler: İlhan Berk, Taymis, çevresel beşeri bilimler, nehir, ekokritik, mekân, tarih, emperyalizm.

GİRİŞ
Çevresel beşeri bilimler, insan ile çevre arasındaki ilişkiyi farklı disiplinlerin katkısıyla ele alan geniş bir çalışma alanıdır. Bu alan çevreyi fiziksel ve doğal özellikleriyle sınırlı görmez. Çevrenin insan yaşamındaki kültürel, tarihsel, toplumsal ve düşünsel karşılıklarını da araştırır. İnsanların çevreyi algılama biçimleri, çevreye yükledikleri anlamlar ve çevreyle kurdukları ilişkiler bu araştırma alanının temel konuları arasında yer alır. Böylece çevre, insanın dışında duran sabit bir alan olmaktan çıkar. İnsan yaşamı ile çevresel süreçler aynı düşünsel çerçevede değerlendirilir. Çevresel Beşerî Bilimlerin ortaya çıkışı da bu geniş bakış açısıyla ilişkilidir. Alan, çevre sorunlarının farklı disiplinlerin katkısıyla ele alınmasını gerekli kılan bir düşünsel zeminde gelişmiştir. "Çevre beşeri bilimleri, çağımızın çevresel zorluklarına yönelik geniş kapsamlı bir yanıt olarak anlaşılmasına olanak verir. Ayrıca çevresel meselelere nitel analiz getirmeyi başaran beşeri ve sosyal bilim disiplinlerinden yararlanarak, çevre beşeri bilimleri, hızlı ve giderek artan bir değişim çağında anlam, değer, sorumluluk ve amaç gibi temel sorularla ilgilenir" (Bird Rose vd. 2012: 1). Bu tanım, alanın çevresel sorunları kültürel ve düşünsel boyutlarıyla birlikte ele aldığını ortaya koymaktadır. Çevre hakkında sorulan soruların anlam, değer, sorumluluk ve amaç gibi kavramlarla ilişkilendirilmesi, beşerî bilimlerin çevre çalışmalarındaki yerini de belirginleştirmektedir. Çevresel Beşerî Bilimlerin gelişim süreci disiplinler arası niteliğini güçlendirmiştir. "2000'lerin başında Avustralyalı akademisyenler tarafından başlatılan bu hareket, o zamandan beri tüm dünyaya yayılmıştır" (Griffiths, 2007).

Zaman içinde edebiyat, tarih, felsefe, antropoloji, sanat, dilbilim ve sosyal bilimler çevre çalışmalarının farklı yönlerini inceleyen alanlar hâline gelmiştir. Bu genişleme çevrenin tek bir disiplinin sınırları içinde açıklanamayacağını göstermektedir.

Çevre, maddi bir gerçekliktir. Aynı zamanda bu gerçekliği oluşturan kültürel anlamların, tarihsel deneyimlerin ve toplumsal ilişkilerin oluştuğu bir alandır. Maddi gerçeklik düzlemde ilerleyen çevreye yönelim; beşeri bilimler, sosyal bilimler ve çevre bilimleri arasındaki üçlü bir işbirliğine dayanan, geniş ve hızla büyüyen bir çalışma alanını kurar. Bu alanı canlandıran bilimsel yönelim, ekolojik krizin kültürel boyutlarına ışık tutmak ve bunları hem eleştirel hem de yaratıcı bir bakış açısıyla yorumlamaktır. Edebiyat, tarih, antropoloji, felsefe, dilbilim, sinema, sanat, sosyal bilimler ve doğa bilimleri arasındaki diyalog, yalnızca çevrenin insanla ilişkisi içinde nasıl düşünülmüş olduğunu analiz etmeye değil, aynı zamanda farklı, daha kapsayıcı, eleştirel ve sürdürülebilir bir kültürü teşvik etmeye de yarayan bir bilgi üretir" (Armiero ve lovino 2020: 40). Bu açıklama, edebiyatın çevresel beşerî bilimler içindeki konumunu anlamak açısından önemlidir. Edebî metinler çevrenin nasıl algılandığını, hangi anlamlarla ilişkilendirildiğini ve insan dışı dünyayla kurulan ilişkinin nasıl biçimlendiğini gösterir. Metinler bu yönüyle çevresel düşüncenin kültürel alanlarından birini oluşturur.

Edebiyat ile çevre arasındaki ilişki ekokritik çalışmaların gelişmesiyle daha belirgin bir kuramsal zemine kavuşur. Ekokritik, edebî metinlerde çevrenin konumunu ve insan ile insan dışı dünya arasındaki ilişkiyi inceleyen bir yaklaşım olarak gelişir. Cheryll Glotfelty, ekokritiği edebiyat ile fiziksel çevre arasındaki ilişkinin incelenmesi olarak tanımlar. Glotfelty'ye göre "eleştirel bir duruş olarak [ekokritizm], bir ayağı edebiyatta, diğer ayağı toprakta durur; teorik bir söylem olarak ise insan ile insan dışı olan arasında arabuluculuk yapar" (Glotfelty ve Fromm, 1996: xix). Bu tanım edebiyat ile çevre arasındaki ilişkinin çift yönlü yapısına dikkat çeker. Edebî metin çevreyi temsil eder. Aynı zamanda insanın çevreyi düşünme ve anlamlandırma biçimini de ortaya koyar. Çevresel Beşerî Bilimler ile ekokritik arasındaki ilişki bu noktada önem kazanır. Ekokritik edebiyat ile fiziksel çevre arasındaki ilişkiye odaklanırken Çevresel beşeri bilimler bu ilişkiyi daha geniş bir disiplinler arası yapı içinde değerlendirir. Çünkü edebiyat, çevrenin kültürel olarak nasıl kurulduğunu anlamaya imkân verir. Tarih çevrenin zaman içinde geçirdiği değişimleri ortaya koyar. Antropoloji insan topluluklarının çevreyle ilişkisini inceler. Felsefe insan ile insan dışı dünya arasındaki etik ve ontolojik sorunları tartışır. Çevre bilimleri ise bu ilişkilerin maddi boyutlarını açıklar. Edebiyat bu disiplinler arasındaki ilişkiye anlatı, imge, dil ve estetik üzerinden katkı sağlar.

Çevresel beşeri bilimin bir diğer savunucuları Iovino ve Oppermann'ın ekolojik yaklaşımı ise edebiyat ile maddi çevre arasındaki ilişkiyi daha geniş bir çerçevede ele alır. Onlara göre "metin olan dünya, anlam yapılarının üreticisi hâline gelir; biyosfer, semiosferle iç içe geçer" (lovino ve Oppermann, 2014: 5). Bu yaklaşım çevrenin metnin dışında duran bir gerçeklik olarak değerlendirilmesini engeller. Dünya ile metin arasında karşılıklı bir ilişki vardır. Maddi çevre anlam üretir. Kültürel ve edebî söylemler de çevrenin algılanma biçimini etkiler. Bu bakış açısı edebiyat incelemesinin kapsamını genişletir. Iovino'nun ifadesiyle çevresel beşeri bilimler "edebiyatı okumak için yeni bir anahtar ve maddi pratikleri ve sosyo-söylemsel yapıları yorumlamak için yeni bir kavramsal model" sunmaktadır (Iovino, 2022: 138). Edebî metin böylece çevresel ilişkilerin izlenebildiği bir alan hâline gelir. Metinde yer alan doğal unsurlar, insan faaliyetleri, maddi nesneler, mekânlar ve tarihsel olaylar bir arada incelenebilir. Bu kuralsal yaklaşım, madde ile söylemlerin iç içe geçmelerini, yalnızca edebiyat ve diğer kültürel biçimler tarafından yeniden yaratıldıkları şekliyle değil, aynı zamanda maddi ifadelerde ortaya çıktıkları şekliyle de" incelemeye imkân verdiğini belirtir. Böyle bir okuma çevreyi metnin arka planından çıkarır ve metnin anlam dünyasının temel unsurlarından biri hâline getirir. Lawrence Buell'in çalışmaları da edebî metin ile çevre arasındaki ilişkinin niteliğini açıklamak açısından önemlidir. Buell, çevrenin edebî metinde arka plan olarak kalmaması gerektiğine dikkat çeker. İnsan dışı çevrenin metindeki varlığı insan deneyimiyle birlikte değerlendirilmelidir. İnsan tarihi ile doğal süreçler arasında da karşılıklı bir ilişki bulunmaktadır. Buell'in çevresel hayal gücü kavramı bu açıdan önem taşır. Çünkü edebiyat, insanın çevreyi nasıl algıladığını ve çevreyle nasıl bir ilişki kurduğunu ortaya koyan bir alan hâline gelir. Edebi metinler, çevresel değerleri anlatan belirli özellikleri anlam hazinesinde barındırır. Ona göre "insan, çevre anlatan metinlerde yalnızca bir arka plan olarak bulunmamalı, insan tarihinin doğal tarihle ilişkisini görünür kılan bir varlık hâline gelmelidir.

İnsan çıkarı metnin tek meşru ilgisi olarak görülmemeli, insanın çevre karşısındaki sorumluluğu metnin etik yöneliminde yer almalıdır. Ayrıca çevre sabit bir unsur olarak değil, değişim ve süreç içinde değerlendirilmelidir" (Buell 1995: 7). Bu nedenle çevre de edebî anlatının biçimini ve anlamını etkileyen bir unsur olarak değerlendirilir.

Çevresel beşeri bilimlerin kuramsal çerçeveleri de İlhan Berk'in *Taymis* şiirinin ekolojik bir çizgide yeniden okunmasına ve değerlendirilmesine uygun bir zemin sunmaktadır. Çünkü, II. Yeni şiirinin güçlü şairlerinden İlhan Berk, ayaklarından yükselen çevrenin mekâna yönelik keşif esintiyle şiirsel diyalektiğin yapısal kavuşumunu gerçekleştirir. Kendisi, "Bir sokak haritacısı gibi çalışırım ben. Beni bir yerin insanları değin, sokakları, caddeleri, evleri, eşyaları da ilgilendirir. İnsanı tarihte, coğrafyada, eşyada görmek, deşmek isterim" (Berk, 2005: 136) tanımlamasında çevresel gezgin ruhunun bakış açısını vurgular. Bu görüşü ışığında şiirinin merkezine Taymis Nehri'ni yerleştirir. Ancak Taymis, şiirde coğrafi bir unsur olarak kalmaz, İngiltere'nin çevre, sosyal hayat, politika, sanat ve ekonomi hatta insanlık tarihinin dönüm noktası olan sanayileşmenin doğumu ve yarattığı çevresel sancılarını anlatır. Taymis şiirinin bu özellikleri, çevresel beşerî bilimlerin edebiyat incelemelerine sunduğu imkânları açık biçimde ortaya koymaktadır. Şiirde çevre, insan yaşamından ayrı değildir. Nehir tarih taşır. Kentle ilişki kurar. Canlı ve cansız unsurlarla aynı çevresel sistem içinde bulunur. Ticaret, ulaşım, emek, kölelik ve emperyalizmle bağlantı kurar. Farklı coğrafyaları aynı şiirsel yapı içinde buluşturur. Bu ilişkiler, Taymis'in şiirdeki konumunun salt bir mekân veya doğa unsuru olarak açıklanamayacağını göstermektedir.

Bu çalışma, söz konusu çevreye yönelik beşeri ilişkileri açıklamak amacıyla Taymis için beş aşamalı bir okuma modeli önermektedir. İlk aşama *ekolojik özneleşme*dir. Bu başlık altında Taymis'in insan dışı bir aktör olarak şiirdeki kuruluşu incelenecektir. İkinci aşama *ekolojik hafıza*dır. Nehir ile tarih, geçmiş ve bellek arasındaki ilişki bu bölümde ele alınacaktır. Üçüncü aşama *kentsel ekoloji*dir. Taymis'in Londra'nın mekânsal ve toplumsal yapısıyla kurduğu ilişki incelenecektir. Dördüncü aşama *tarihsel ekoloji*dir. Şiirde farklı dönemlerin aynı çevresel alan içinde buluşması değerlendirilecektir. Beşinci aşama *politik ekoloji*dir. Taymis'in Tuna, Boğaziçi, Haliç ve farklı coğrafyalarla kurduğu bağlantılar bu başlık altında değerlendirilecektir. Çalışmanın araştırma yöntemlerini ve bulgularını kapsayan beş aşama birbirinden kopuk değildir. Her aşama Taymis'in şiirdeki anlam alanını biraz daha genişletir. Taymis önce bir nehir olarak belirir. Ardından hareket eden bir varlık hâline gelir. Tarihle ilişki kurar. Kentin içine girer. Farklı dönemleri taşır. Ticaret ve emperyalizmle bağlantı kurar. Sonunda farklı coğrafyaları birbirine bağlayan geniş bir çevresel ağ içinde görünür. Bu hareket, şiirin çevreyi kurma biçimini de ortaya koyar.

ARAŞTIRMA VE BULGULAR

1. Ekolojik Özneleşme: Taymis'in Bir Çevresel Aktör Olarak Kuruluşu

Çevreyi mekân olarak kurgu evrenine yerleştiren edebi metinler, "doğanın anlamı üzerinde uzlaşmaya çalışır; bu anlam metin içerisinde, ancak melez imgeler ve sorunlu temsiller de içine dahil edildiğinde referans olarak kabul edilebilir. Yani doğa, bizim dışımızda duran bir varlık değildir; sınırlanabilir, bir kez belirlenmiş ve değişmez bir nesne değildir; aksine, bir kadrajın sonucudur. Farklı edebi eserler farklı çerçeveler sunar; bu nedenle 'doğa', bakir bir orman, kirlenmiş bir arazi ya da yolların artık şehir olmadığı, henüz kırsal da olmadığı bir ara bölge olabilir" (Scaffai, 2017: 71-72). Edebi metinlerdeki çevresel yapıya temasın önemini inceleyen Lawrence Buell çevresel edebiyat yaklaşımında, çevrenin edebi metinde yalnızca olayların gerçekleştiği bir arka plan olarak kalmaması gerektiğini belirtir. İnsan dışı çevre, metnin anlam yapısına katılan etkin bir unsur hâline gelir. Bu yaklaşımda insan tarihi ile doğal tarih arasında da doğrudan bir ilişki kurulur. Çünkü "Çevre, insan deneyiminin dışında duran bir alan olarak değerlendirilmez. İnsan ile çevre arasındaki karşılıklı ilişki edebi metnin temel unsurlarından biri hâline gelir" (Buell 1995: 7). İlhan Berk'in Taymis şiiri de bir nehrin çevreye dair bir kavram olmanın yanında şehir ruhunu taşıyan ekolojik bir özne varlığı olmasının yanında insanlık ve çevre arasındaki ayrılmaz bağlantının ekolojik sembol aynasıdır. Şiirin sembolik çevre öznesi olan Taymis Nehri, dizelerin anlam düğümünü pasif bir doğal unsur olarak kurmaz. Şiir öznesi nehre, *"Uzun boylu muydu Turner? / Yavaş yavaş oynuyor omurgaları Taymis'in"* (Berk, 2021: 38) dizeleriyle bedensel ve hareket özellik kazandırır. Bu durum nehrin insan bedenine ait bir özellik üzerinden düşünülmesini sağlar. Şiirdeki özneleşme eylemi, şiirin ilerleyen bölümlerinde farklı biçimlerin zuhur etmesini sağlar.

Bedeniyle hareket ivmesi kazanan Taymis; köprülerle, kanallarla, sokaklarla, istasyonlarla ve Londra'nın farklı bölgeleriyle temas eder. Greenwich'e çıkar, Blackwall'da oyalanır, doklara uğrar ve bir kanala girip çıkar. Bu hareketler nehrin çevresindeki mekânlarla kurduğu ilişkiyi görünür kılar. Taymis kent içinde hareket eden bir varlık olarak belirginleşir. Kent, nehrin karşısında duran bağımsız bir yapı değildir. Nehir ile kent aynı çevresel sistem içinde bulunur.

Taymis, şiir içerisinde insanlarla kurduğu ilişkide de özneleşme eylemini göstermeye devam eder. Şiirin ilk bölümünde karabatak, ispermeçet mumu satan adam, mektubuna pul yapıştıran kişi ve nehir çevresindeki diğer unsurlar aynı şiirsel alan içinde yer alır. Daha sonraki bölümlerde işçiler, balıkçılar, gemiler, vinçler bu çevresel yapıya katılır. Taymis bütün bu unsurların arasında hareket eder. Böylece nehir ile insan dünyası arasında karşılıklı bir ilişki kurulur. Hatta anlatıcı, *Taymis: Neredeyim? diye* aklından geçiriyor" (Berk, 2021: 46) söylemi ile özneleşme durumunu bir adım daha ileri aşamaya ulaştırarak nehre düşünen, bulunduğu yeri sorgulayan ve çevresiyle ilişki kuran bir kimliğe eriştirir. Şiirde Taymis'in özneleşmesi tarih ile kurduğu ilişkide de belirginleştirilerek aktarımı yapılır. *"Ben bir nehrin tarihine çalışıyorum"* (Berk, 2021: 39) söylemiyle şiir öznesi, nehri tarihsel bir varlık olarak konumlandırır. Anlatıcı, Taymis'in tarihini insan tarihinden ayırmaz. Londra'nın tarihsel mekânları, ticaret yolları, donanma, demiryolları, kölelik ve emperyalizm nehrin çevresinde görünür hâle geldiğini vurgular. Bu nedenle Taymis'in varlığı doğal çevre ile insan tarihinin kesiştiği bir noktada şekillenir. Bu bağlamda Taymis'in şiirdeki özneleşmesi, nehre insan özellikleri verilmesinden ibaret değildir. Daha geniş bir çevresel ilişkinin kurulması söz konusudur. Taymis hareket eder, mekânlarla ilişki kurar, tarih taşır ve farklı coğrafyalara uzanır. Şiirin sonunda *Avustralya, Hindistan, Afrika, Karayipler* ve başka coğrafyaların Taymis'in düşünsel hareketine dâhil edilmesi, nehrin çevresel varlığını geniş coğrafyalara ulaştırır. Nehir böylece belirli bir coğrafyada bulunan nehir olmaktan çıkar ve farklı insan, mekân ve tarihlerin kesiştiği bir çevresel özne hâline gelir.

Şiirsel ekolojik çevre yaratımı, "anlatıcı öznenin kendisiyle yaşadığı gerçeklik arasında inşa ettiği yeni bir evrendir" (Ecevit, 2002: 30). Bu ekolojik özneleşme yaklaşımı açısından değerlendirilen Taymis, insan dışı çevrenin metinde etkin bir konumuna ulaşan şiir kavramı olarak okunabilmesini gerçekleştirir. Çünkü nehir insan tarihinin dışında değildir. Kentin, ticaretin, ulaşımın ve emperyal ilişkilerin içinden geçer. Şiirin anlam dünyasını taşıyan temel unsurlardan biri hâline gelir. Taymis'i bedenleştiren ekolojik özneleşme eylemi, nehrin kişileştirilmesinden daha geniş bir anlam taşır. Böylelikle Taymis; şiirin çevresel, tarihsel ve kültürel yapısını bir arada tutan etkin bir özne olarak kurulumunu sağlar.

2. Ekolojik Hafıza: "Bir Nehrin Tarihine" Çalışmak

Şiirin ikinci önemli boyutu, Taymis'in taşıdığı hafızanın merkezi anlam kapsamıdır. Bu boyutu vurgulayan önemli dizelerinden biri şudur: *"Ben bir nehrin tarihine çalışıyorum Elsworthy'de 1962'lerde bir evde"* (Berk, 2021: 39). Burada nehir ile tarih arasında doğrudan bir ilişki kurulur. Çünkü anlatıcı, özneleşen bir nehrin tarihini araştırır. Bu ifade şiirin hafızaya yönelik temel yaklaşımını da açıklar. Tarih genellikle insan topluluklarının yaşadığı olaylar üzerinden anlatılır. İlhan Berk ise tarihi nehrin çevresinde düşünür. Böylece Taymis bir tarih taşıyıcısı hâline gelir. Londra'nın tarihi ile Taymis'in tarihi birbirinden ayrılmaz. Çünkü Londra'nın şiirdeki çevresel peyzajının "kronotop olarak çağrılması; her nişin ve yer adının ortak bir anlatılar bütünü içinde sembolik anlam taşıdığı, toplumsal olarak paylaşılan bir çevresel zaman-mekân olarak düşünülmesi" (Buell, 2017: 108) gerekçesine kaynaklık etmektedir.

Şiir öznesinin çevreye dair tarihi yönelim düşüncesi, insan tarihi ile doğal çevrenin tarihi arasında bir bütünleşme yoluna girer. Nitekim çevre değişirken insan toplulukları da değişir. İnsanların kurduğu şehirler, ulaşım sistemleri ve ekonomik ilişkiler de içinde yaşadıkları çevreyi dönüşüme uğratır. Şiirde de bu ilişki Taymis'in farklı mekânlarla bağlantısı üzerinden aktarılır. Anlatıcı Londra'daki Taymis'ten İstanbul'daki Boğaziçi'ne geçer. *"Taymis'i alıp çıkıyorum sonra belki de bir başka suyu Boğaziçi'ni"* (Berk, 2021: 39) dedikten sonra da Boğaziçi'nin çevresindeki kültürel unsurlar sıralanır. Yalılar, sedirler, perdeler, kanarya, mutfak, eşyalar ve vapur aynı şiir bölümünde yer alır. Boğaziçi'nin yansıttığı su mekânı, kültürel belleğin taşıyıcısı hâline gelir. Anlatıcı şiir dair ekolojik hafızayı, Taymis ile Boğaziçi arasında toplumsal bir bağlantı kurarak aktarır. İki farklı şehir, iki farklı tarih ve iki farklı kültürel çevre su üzerinden anlamsal olarak yan yana gelmeyi başarır. Şiirin başka bir bölümünde de anlatıcı, *"Tuna'ya benziyor burda Taymis/ İnce derili/ Ve ürkek Haliç'in Ortodoks yakası gibi"* (Berk, 2021: 40) söylemi ile Taymis, Tuna ve Boğaziçi arasında bir bellek ilişkisi yaratır.

Taymis, anlatıcıya başka suları hatırlatır. Başka sular da Taymis'in kavramsal anlam genişlemesine aracı olur. Bu açıdan sular üzerinden yaratılan ekolojik hafıza, şiirin önemli anlamlandırma kaynaklarından biridir. Çünkü çevre geçmişi taşır ve su kaynakları da insan tarihinin dışında duran bir varlık değildir. Tarihin içinden geçer ve tarihin hafızasını kendi hareketi içinde taşıyarak uzak diyarlara aktarır. Uzak coğrafyaların aktarıcısı olan su hafızası, şiire girer. Böylece suyun hareketi şiirin anlam üretme biçimine dönüşür. Şiir içerisinde hidro-kültürel ağ, salt ekolojik olarak değil; tarih, kültür ve kent üçgeninde ekolojik bağlantılılık düşüncesinde metnin özgül yapısına uyarlayan bir kavram olarak kullanılır.

3. Kentsel Ekoloji: Taymis ve Londra

Kentlere yönelik geliştirilen ekokritik, doğal çevre ile kent arasındaki ilişkiyi sorgulayan bir yaklaşımdır. Bu yaklaşımın temel amacı, "kentin doğasına odaklanmayı keskinleştirmek ve kentsel ekokritiğin bileşenlerini incelemektir" (Bennett ve Teague, 1999: 4). Özellikle kent sakinlerinin de çevresel ekosistemlerin dışında yer almayacağını vurgulayarak kentsel yaşamın öznelerinin de çevresel ilişkiler içinde değerlendirilmesini vurgular. Taymis şiirinde de çevre ile kent arasında keskin bir ayrım yoktur. Nehir sürekli Londra'nın insan yapımı çevresiyle birlikte ele alınarak, anlam kazanır. Bu amaç doğrultusunda; şiirin çeşitli bölümlerinde kent yaşamının çevresel yapılanmasını gösteren köprüler, istasyonlar, vinçler, doklar, kanallar, sokaklar ve evler görülür. Özellikle şu bölüm önemlidir: *"İstasyonu, vinçleri, deri kokularını geçiyor. Oltasını atıyor"* (Berk, 2021: 43). Bu dizelerde üç farklı çevresel unsur aynı anda bulunur. Endüstriyel yapıların yanında nehir ve balıkçılık vardır. Şehir ile su, şiir evreninde de birbirinden ayrılmaz. Anlatıcının anlamlandırma şekli, çevreyi sabit bir arka plan olarak görmeyen yaklaşımı aksettirir. Çevre değişen ve insan yaşamıyla karşılıklı ilişki kuran bir alandır. Taymis de böyle bir çevresel süreç içinde hareket eder.

Şiirin ilerleyen bölümünde Taymis, *"Blackwall'da oyalanıyor doklara uğruyor bir kanala girip çıkıyor"* (Berk, 2021: 46). Bu ifade nehrin kent altyapısıyla ilişkisini açık bir şekilde gösteriyor. Böylelikle Londra'nın ekonomik hayatının da Taymis'in çevresinde şekillendiği vurgulanır. Nitekim limanlar, gemiler, balıkçılar ve ticari hareketlilik nehirle bağlantılıdır. Nehir bu sistemin dışındaki doğal bir unsur değildir. Sistemin içindedir. Bu nedenle Taymis, kentsel ekoloji açısından okunabilir bir gücü üstlenir. Kent burada doğanın karşısında değildir. Kent ve nehir aynı çevresel sistemin parçaları hâline gelir. Bu yaklaşım aynı zamanda ekokritik düşüncenin doğa yazınıyla sınırlı kalmayan yönünü gösterir. Sonuç olarak çevresel edebiyat çalışmaları zamanla kent, endüstri, hayvanlar, mimari ve teknoloji gibi alanları da kapsayan bir çizgide yerleşim alanı bulur.

4. Tarihsel Ekoloji: Nehirde Biriken Zaman

Nehirlerin tarihsel konumu, onları yalnızca doğal oluşumlar olarak değerlendiren yaklaşımların ötesine taşımıştır. Nehirlerin sahip olduğu "tarihsel aktörler ve coğrafi yerler" (Benson, 2025: 99) kendisini kapsayan aktör olarak şiirde Taymis Nehri'ni seçmiştir. Bu seçilim, Taymis'i insan tarihinin üzerinde gerçekleştiği pasif bir zemin olmaktan çıkarır ve tarihsel süreçlerin oluşumuna katılan ve bu süreçlerin izlerini taşıyan bir çevresel varlık olarak düşündürür. Anlatıcı nehir akışında anlattığı şiirsel zamanı, doğrusal bir boyutta aktarmaz. Farklı tarih dönemleri aynı şiirsel mekânda bir araya getirerek okura sunar. Şiirde Roma dönemi, Victoria dönemi, Edwardlar, Orta Çağ, modern Londra ve 1962 aynı çevrenin eş zamanlı unsuru gibi sunulur. Örneğin: *"Sonra da Romalılar zamanında gibi soyunuyor/ 1962 sabahı mı bu? Kapalı Sisli/ Ve manyetik iğneyi Araplardan Alıp Avrupalılara veriyor 1180'e doğru/ Londra Caddesi'ni aydınlatıyor XV. yüzyılda"* (Berk, 2021: 42-44-46). Bu ifadeler arasındaki zaman farkı oldukça geniştir. Şiir bu farkı ortadan kaldırır. Taymis burada zamanları birbirine bağlayan bir unsur hâline gelir. Roma döneminden modern Londra'ya kadar farklı tarihsel katmanlar nehrin çevresinde toplanır. Bu durum tarihsel ekoloji kavramıyla açıklanabilir. Doğal çevrenin tarihi ile insan tarihinin aynı zaman düzleminde düşünülmesidir bu. Nehir değişen toplumların, ekonomik yapıların ve şehirlerin arasından geçmeyi başarır.

Şiirin özellikle ikinci bölümünde Victoria dönemine ilişkin göndermeler de bu tarihsel katmanlaşmayı sürdürür. *"Yüzü gibi Kraliçe Victorya'nın -ki uzaklara bakmıştır hep /Ve hep sol eliyle görmüştür işini/ Ve sabah hep o sabah Honley yolunda. İvedi /Ve daha küçük ayakları /Ama hırçın St. Georges'da ve Rotten Roow'da /Çıkarmadan girer pabuçlarını kiliseye. /Ve hep ayakta durur /Ve İsa'yı kıskanır"* (Berk, 2021: 44). Şiirin bu bölümündeki Kraliçe Victoria, Londra'nın mekânları, dini yapılar, gündelik yaşam ve doğal unsurlar aynı anlatı içinde kavram olarak anlam düzlemini kurar. Taymis'in akış yönünde beliren tarihi gösterim bir arka plan olarak mevcudiyet bulmaz.

Bu tarihi kavramlar, nehir suyunun hareketiyle birlikte anlatıcının biliş dünyasında yeniden anlam çerçevesinde kurulur. Bu doğrultuda Taymis'i tarihsel bir çevre arşivi olarak okumak ve değerlendirmek mümkündür.

5. Politik Ekoloji: Taymis ve Emperyal Dolaşım

Politik ekoloji, insan ile çevre arasındaki ilişkiyi güç, ekonomi, tarih ve toplumsal eşitsizlikler üzerinden ele alan bir yaklaşımdır. Çevresel süreçler bu bakışta siyasal ve ekonomik ilişkilerden ayrı değerlendirilmez. Çevrenin kullanımı, dönüştürülmesi ve paylaşılması belirli güç ilişkileri içinde gerçekleşir. Ayrıca "yaşam alanını diğer canlılar ile paylaşan doğa, kendi egemen kolonisini kurmak isteyen dominant güçlerle her defasında temasa girmek zorunda kalır" (Arslan ve Gökçe Yiğit, 2024: 206). Politik ekoloji bu ilişkilerin çevresel sonuçlarını incelemektedir. Bu yaklaşım, çevresel değişimin "Çevresel meseleler yalnızca çevresel sorunlar olarak değerlendirilemez; bu meseleler aynı zamanda politik ve tarihsel süreçlerle bağlantılıdır ve derin toplumsal eşitsizlikler içerir" (Malik vd., 2026: 1). Böyle bir çerçeve, doğanın ekonomik ve siyasal sistemlerden bağımsız bir alan olarak görülmesini engeller. Çevre, iktidarın uygulandığı ve ekonomik ilişkilerin biçimlendirdiği maddi bir alana dönüşür. Bu nedenle politik ekoloji, insan toplulukları ile insan dışı dünya arasındaki ilişkilerin arkasında bulunan güç yapılarını görünür hâle getirir. Bu yaklaşım Taymis şiirinin özellikle ikinci bölümünde belirginleşir. Taymis burada Londra'nın içinden geçen bir nehir olmanın ötesine taşınır. Nehir, İngiltere'nin ticari, askerî ve sömürgeci hareketlerinin izlerini üzerinde taşıyan bir çevresel aktörü olur. Şiirde farklı coğrafyaların art arda sıralanması bu dönüşümün ilk göstergesidir. Taymis'in hareketi Londra sınırlarında tamamlanmaz. Taymis aracılığıyla şiir anlatıcısı; *Seylan'ı, Malta'yı, Jamaica'yı, Bahama'yı, Bermuda'yı, Cebelitarık'ı Kanada'yı* düşünür. Ardından *Avustralya'yı, Yeni Zelanda'yı, Hindistan'ı ve Afrika'yı* belleğinde canlandırır. Coğrafi isimlerin bu yoğun kullanımı, Taymis'in tek bir kente ait nehir olmaktan çıktığını gösterir.

Taymis'in anımsatıcı özelliği aslında İngilizlerin sömürgecilik faaliyetleriyle deniz aşırı hareketlerinin ulaştığı geniş coğrafyaları aynı şiirsel yapı içinde birbirine bağlanmasına aracıdır. Bu bağlamda Taymis'in hareketi coğrafi bir akış olarak okunamaz. Nehrin akışı, ticaret, askerî güç, ulaşım ve sömürgecilik ilişkilerinin akışıyla birlikte düşünülür. Şiirde *British Navy* ifadesinin hemen ardından *Süryanilerin Eski Tarihi, Hudson By Company ve öbür kumpanyaları, demiryollarını ve buharlı gemileri* ifadeleri gelir. Askeri güç, ticaret şirketleri, ulaşım teknolojileri ve tarih aynı şiirsel dizge içinde yer alır. Böylece Taymis'in çevresindeki maddi dünya, ekonomik ve siyasal sistemlerle birleşir. Nehir bu sistemlerin dışında değildir. Onların dolaşımını sağlayan çevresel yapılardan biri olarak görünür. Bu ilişkinin kapsamı şiirde kölelik, emek ve emperyalizm kavramlarının Taymis'in tarihine dâhil edilmesiyle genişler. Şiirdeki *"kürek mahkûmlarını ve kadın ve erkek şapkalarını ve köleliği ve öküzü ve atı ve Emeğin Tarihi'ni ve John Locke'u, Nasıriyeli İsa'yı ve: Zenginbiradamıncennetegirmesibirdeveniniğne- deliğindengeçmesindenzordur! dediğini ve I., II. Enternasyonalleri ve bir çamurayaklıdev'i (emperyalizm adlı) ve kendi pis tarihini"* (Berk, 2021: 42) söylemiyle anlatıcı; insan, hayvan, emek ve kölelik bu dizelerde aynı çevresel yapı içinde buluşturur. Böylece Taymis'in tarihi doğal çevrenin geçmişi olmaktan çıkar ve İngiltere'nin toplumsal, ekonomik ve siyasal tarihiyle birleşir. Bu durum *bir çamurayaklıdev'i (emperyalizm adlı)* ifadesinde daha belirgin hâle gelir. Emperyalizm burada soyut bir kavram olarak bırakılmaz. *Çamurayaklıdev* sözü emperyal gücü somut bir varlık gibi gösterir. *Dev* sözcüğü gücü ve genişlemeyi, *çamur* sözcüğü ise bu gücün dayandığı sorunlu tarihi düşündürür. Kölelik, emek, ulaşım ve ticaret gibi unsurlar da bu imgenin anlamını genişletir. Şiirde geçen "ve kendi pis tarihini" ifadesi bu açıdan önemlidir. Taymis'in taşıdığı tarih, İngiltere'nin siyasal ve ekonomik gücünün yanında sömürgecilik, kölelik ve emek ilişkilerini de içerir. Nehir geçmişin gücünü ve bu gücün yarattığı çatışmaları birlikte taşır.

Taymis'in Londra'dan uzak coğrafyalara doğru ilerlemesi şiirin sonunda daha geniş bir çevresel ilişki kurar. *Yeniden Avustralya'yı, Hindistan'ı, Afrika'yı, adaları, Karaibler'i* düşünen Taymis, İngiltere'nin deniz aşırı bağlantılarını aynı şiirsel yapı içinde bir araya getirir. Bu coğrafyalar arasındaki ilişki yalnızca bir yer sıralaması değildir. Ticaret, deniz taşımacılığı, askeri güç ve sömürgecilik bu bağlantıların temelini oluşturur. Şiirin sonunda yer alan anlatıcının *Allah İngiliz için çalışıyor!* ifadesi tarihsel yapıya ironik bir anlam kazandırır. İngiliz gücünün genişlemesi ilahi bir destekle açıklanır. Hemen ardından gelen *Uzanıyor/Düşüyor kolu rüzgârın* dizeleri bu gücü insan dışı dünyanın hareketiyle karşılaştırır. Taymis bu karşılaşmanın merkezinde bulunur.

Nehir İngiltere'nin ekonomik ve siyasal gücünün izlerini taşır. Aynı zamanda bu gücün tarihsel sonuçlarını görünür kılar. Böylece Taymis, politik ekoloji açısından çevre, ekonomi, siyaset ve tarih arasındaki ilişkinin birlikte okunabileceği bir şiir hâline gelir. Taymis'in akışı suyun hareketini sürdürürken insanların, malların ve ekonomik gücün hareketini de düşündürür. Nehir bu nedenle emperyal dolaşımın pasif bir tanığı değildir. Emperyal ilişkilerin içinden geçen ve bu ilişkilerin tarihsel izlerini taşıyan çevresel bir aktördür.

SONUÇ

İlhan Berk'in Taymis şiiri; nehir, insan ve kent ilişkilerini farklı sosyolojik bağlamlar etrafında birleştiren çevresel bir edebi yapıyı temsil eder. Şiirde Taymis, farklı zamanları, mekânları ve toplumsal deneyimleri birbirine bağlayan çevresel bir aktör olarak belirginleşmektedir. Nehrin hareketi, çevresindeki kentsel yapıların ve insan faaliyetlerinin yanı sıra tarihsel olayların, kültürel belleğin ve ekonomik ilişkilerin de şiirsel anlam alanına taşınmasını sağlamaktadır. Bu doğrultuda Taymis'in şiirdeki konumu, çevre ile insan yaşamı arasındaki karşılıklı etkileşimin merkezinde şekillenmektedir. Beş aşamalı okuma modeli üzerinden gerçekleştirilen değerlendirme, Taymis'in şiir boyunca etkin bir çevresel özne olarak kurulduğunu göstermektedir. Nehrin hareket etmesi, bulunduğu yeri sorgulaması, farklı mekânlarla temas kurması ve tarih taşıması, ona şiirsel yapı içerisinde etkin bir konum kazandırmaktadır. Bu özneleşme, insan dışı çevrenin insan tarihi, kent ve toplumsal yaşamla karşılıklı ilişkiler içerisinde ele alınmasına dayanmaktadır. Taymis böylece şiirin farklı anlam katmanlarını birbirine bağlayan temel çevresel unsurlardan biri hâline gelmektedir.

Ekolojik hafıza bağlamında Taymis, geçmiş ile bugün arasında süreklilik oluşturan bir bellek alanı olarak ortaya çıkmaktadır. *Bir nehrin tarihine* çalışma düşüncesi, tarihin çevresel varlıklarla ilişkili biçimde okunabileceğini göstermektedir. Taymis'in Boğaziçi, Tuna ve Haliç gibi farklı su alanlarıyla ilişkilendirilmesi, suyun farklı coğrafyalar arasında kültürel ve tarihsel bağlantılar oluşturmasını sağlamaktadır. Bu bağlamda nehir, farklı şehirlerin, kültürlerin ve tarihsel deneyimlerin aynı şiirsel yapı içerisinde buluşmasına aracılık eden bir hafıza taşıyıcısı niteliği kazanmaktadır. Suyun hareketi, şiirin düşünsel hareketiyle birleşerek coğrafyalar arasında bir ekolojik bağlantılılık meydana getirmektedir. Kentsel ekoloji açısından değerlendirildiğinde Taymis ile Londra arasında karşılıklı bir çevresel ilişki bulunduğu görülmektedir. Köprüler, istasyonlar, doklar, kanallar, vinçler, gemiler, sokaklar ve evler nehir çevresindeki yaşamın farklı unsurlarını oluşturmaktadır. Taymis bu yapıların arasından geçerken Londra'nın toplumsal ve ekonomik yaşamıyla bütünleşmektedir. Nehir ile kent arasındaki ilişki, doğal ve insan yapımı çevrenin aynı ekolojik sistem içerisinde değerlendirilmesine imkân vermektedir. Böylece Londra, çevresel süreçlerden bağımsız bir kent olarak değil, nehirle sürekli etkileşim hâlinde bulunan bir yaşam alanı olarak şiirde anlam kazanmaktadır.

Tarihsel ekoloji açısından şiirin dikkat çekici yönlerinden biri, farklı tarihsel dönemleri Taymis çevresinde bir araya getirmesidir. Roma dönemi, Orta Çağ, Victoria dönemi, Edward dönemi ve modern Londra gibi farklı zaman katmanları şiirin akışı içerisinde karşılaşmaktadır. Taymis bu dönemler arasında süreklilik sağlayan bir çevresel hafıza alanı oluşturmaktadır. Böylece nehir, değişen toplumların, kentlerin, ekonomik yapıların ve kültürel deneyimlerin arasından geçen tarihsel bir varlık olarak görünür hâle gelmektedir. Doğal çevrenin tarihi ile insan tarihinin kesişmesi, şiirin zaman anlayışını da doğrusal bir yapıdan çıkararak katmanlı bir hâle getirmektedir. Politik ekoloji bağlamında Taymis'in anlam alanı Londra'nın sınırlarını aşarak farklı coğrafyalara ulaşmaktadır. Ticaret, deniz ulaşımı, askerî güç, kölelik, emek ve emperyalizm gibi unsurların nehir çevresinde bir araya gelmesi, çevresel süreçlerin ekonomik ve siyasal ilişkilerle bağlantısını ortaya koymaktadır. *Malta, Jamaika, Bahama, Bermuda, Cebelitarık, Kanada, Avustralya, Yeni Zelanda, Hindistan* ve *Afrika* gibi coğrafyaların şiirde Taymis ile ilişkilendirilmesi, nehrin geniş bir tarihsel ve coğrafi dolaşım ağı içerisinde düşünülmesini sağlamaktadır. *British Navy, ticaret şirketleri, demiryolları* ve *buharlı gemilerle* ilgili göndermeler de bu dolaşımın ekonomik, askeri ve teknolojik boyutlarını görünür hâle getirmektedir. Şiirde kölelik, emek ve emperyalizm kavramlarının Taymis'in tarihine dâhil edilmesi, nehrin çevresel varlığının toplumsal ve siyasal süreçlerle birlikte düşünülmesini mümkün kılmaktadır. *Çamurayaklıdev* biçimindeki emperyalizm imgesi, İngiliz emperyal gücünün şiirsel düzlemde somutlaştırılmasını sağlarken *kendi pis tarihini* ifadesi bu tarihsel gücün taşıdığı çatışmaları ve sorunları da görünür hâle getirir.

Bu yönüyle Taymis'in akışı, insanların, malların, teknolojilerin ve iktidar ilişkilerinin hareketiyle birlikte anlam kazanır. Nehir, emperyal dolaşımın gerçekleştiği çevresel ağın önemli bir parçası olarak şiirin politik anlamını genişletmektedir.

Bütün bu bulgular birlikte değerlendirildiğinde, Taymis şiirinde çevre ile insan yaşamı arasında karşılıklı ve sürekli bir ilişki kurulduğu görülmektedir. Ekolojik özneleşme Taymis'in etkin bir çevresel aktör hâline gelmesini; ekolojik hafıza nehrin tarihsel ve kültürel deneyimleri taşımasını; kentsel ekoloji nehir ile Londra arasındaki karşılıklı bağı; tarihsel ekoloji farklı zaman katmanlarının nehir çevresinde birleşmesini; politik ekoloji ise Taymis'in ticaret, emek, kölelik ve emperyalizmle bağlantısını açıklamaktadır. Bu aşamalar bir arada düşünüldüğünde Taymis'in şiirdeki anlam alanının çevresel, tarihsel, kültürel, kentsel ve politik boyutların kesişiminde oluştuğu ortaya çıkmaktadır. Sonuç olarak İlhan Berk'in şiiri, çevresel beşerî bilimlerin sunduğu disiplinler arası perspektif açısından kapsamlı bir okuma imkânı sunmaktadır. Taymis'in akışı, doğal çevre ile insan tarihinin birbirini biçimlendiren yapısını ortaya koyan; çevreyi tarih, kültür, kent, ekonomi ve siyasetle birlikte değerlendiren güçlü bir ekolojik şiir örneği olarak değerlendirilebilir.

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DOLUNAYDA AÇIĞA ÇIKAN ÖTEKİ BEN: MARK TURNER'IN KÜÇÜREK ÖYKÜSÜNDE ÇİFT KARAKTERLİLİK VE GECİKTİRİLMİŞ ANLAM

THE OTHER SELF REVEALED UNDER THE FULL MOON: DUAL CHARACTERIZATION AND DELAYED MEANING IN MARK TURNER'S MICROFICTION

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ÖZET

Küçürek öykü, sınırlı anlatı hacmi içerisinde yoğun anlam katmanları üreten eksiltme, çağrışım, simgesel anlatım ve sürpriz son gibi tekniklerden yararlanan bir anlatı türü olarak karşımıza çıkar. Mark Turner'ın *Bölünmüş Kişilik* adlı küçürek öyküsü, romantik bir yakınlaşma görüntüsüyle başlayan olay örgüsünü şiddet, ölüm ve dönüşüm çağrışımlarıyla tamamlayarak insanın görünen kimliği ile bastırılmış karanlık yönü arasındaki çatışmayı konu edinmektedir. Öyküdeki erkek karakterin toplumsal çevreye sunduğu uyumlu kimlik ile belirli koşullar altında ortaya çıkan yırtıcı benliği arasındaki karşıtlık, çift karakterlilik kavramı çerçevesinde dikkat çekici bir yapı oluşturmaktadır. Buradaki bölünmüşlük, psikiyatrik anlamda bir kişilik bozukluğuna indirgenmeden, edebi metinde aynı özne içerisinde birbiriyle bağdaşmayan iki farklı varoluş biçiminin yan yana bulunması şeklinde ele alınabilir. Anlatının başlangıcında güven veren, kusursuz ve arzu edilir bir erkek imgesi oluşturulurken metnin sonunda bu görüntünün gerisinde saklanan şiddet eğilimi görünür hale gelir. Dolunay, kurt, kan ve ölüm çevresinde oluşan simgesel alan, karakterin bastırılmış öteki beninin açığa çıkmasını temsil eder. Bununla birlikte öykünün temel etkisi yalnızca karakterdeki ikili yapıdan değil, anlamın bilinçli biçimde ertelenmesinden kaynaklanmaktadır. Dönüşüm ve saldırı anlarının anlatı dışında bırakılması okuru boşlukları tamamlayan etkin bir yorumlayıcıya dönüştürür. Son bölümde verilen göstergeler, başlangıçta romantik ve sıradan görünen ayrıntıları geriye dönük olarak yeniden anlamlandırır. Böylece çift karakterlilik metnin romantik anlatıdan gotik ve tekinsiz bir anlatıya dönüşen yapısını belirlemektedir. Bölünmüş Kişilik görünüş ile gerçeklik, uygarlık ile yabanıllık, insan ile hayvan ve toplumsal persona ile bastırılmış öteki arasındaki sınırları küçürek öykünün yoğunlaştırılmış anlatım imkânlarıyla tartışmaya açmaktadır.

Anahtar Kelimeler: Küçürek öykü, çift karakterlilik, öteki ben, geciktirilmiş anlam, persona, anlatısal eksilti, gölge benlik.

ABSTRACT

The short story emerges as a narrative genre that makes use of techniques such as ellipsis, association, symbolic narration, and surprise endings to produce dense layers of meaning within a limited narrative space. Mark Turner's short story titled Split Personality addresses the conflict between the visible identity of the individual and the repressed dark side by completing a plot that begins with the appearance of romantic intimacy through associations of violence, death, and transformation. The contrast between the male character's harmonious identity presented to his social environment and his predatory self that emerges under certain conditions creates a remarkable structure within the framework of dual characterization. The division here can be considered not by reducing it to a personality disorder in the psychiatric sense, but as the coexistence of two incompatible forms of existence within the same subject in the literary text. While a trustworthy, flawless, and desirable male image is created at the beginning of the narrative, the tendency toward violence hidden behind this image becomes visible at the end of the text. The symbolic field formed around the full moon, the wolf, blood, and death represents the emergence of the character's repressed other self. However, the fundamental effect of the story derives not only from the dual structure of the character but also from the deliberate postponement of meaning.

The omission of the moments of transformation and attack from the narrative turns the reader into an active interpreter who completes the gaps. The signs presented in the final section retrospectively reinterpret the details that initially appear romantic and ordinary. Thus, dual characterization determines the structure of the text as it transforms from a romantic narrative into a Gothic and uncanny narrative. Split Personality opens up for discussion the boundaries between appearance and reality, civilization and wildness, human and animal, and the social persona and the repressed other through the condensed narrative possibilities of the short story.
Keywords: Short story, dual characterization, the other self, delayed meaning, persona, narrative ellipsis, shadow self.

Küçürek Öykünün Anlatısal Eksiltisi Turner Ve Bölünmüş Kişilik

"Adam mükemmeldi. Kadın büyülenmişti. Ama kafası karışmıştı.
"Diğer ilişkilerin neden bu kadar kısa sürdü?" diye merakla sordu yürürlerken.
Adam bakışlarını ona doğrulttu.
"Şey, benim küçük bir sorunum var..."
Daha sonra dedektif yüzünü buruşturarak genç kızın dolunayda
kanlar içindeki
korkunç cesedine baktı.
Uzaklarda bir kurt uludu." (Turner, 1995: 45)

Küçürek öykünün en belirgin özelliklerinden biri, az sayıda sözcükle geniş bir anlam alanı oluşturabilmesidir. Tür, kısa hacmi gereği olayların ayrıntılı biçimde açıklanmasından ziyade okuru çağrışımlara, boşluklara, sessizliklere ve özellikle metin içinde seçilmiş göstergelere yönlendirmekte anlatıyı okurun tamamlamasını ve kurgulamasını istemektedir. Yine "küçürek öyküde, olay örgüsünden çok yarım kalmışlık hissi veren ayrıntıya dayalı gerçekler ve şaşırtıcı hatta şok edici bir sonuç/kapanış ön plandadır" (Koçsoy, 2018: 117). Bu nedenle küçürek öyküde söylenmeyenler çoğu zaman söylenenler kadar önemlidir. Geleneksel anlatılarda karakter, olay ve mekân hakkında uzun açıklamalarla oluşturulan anlam, küçürek öyküde birkaç sözcüğün yan yana gelişinden doğabilir. Bir sıfat, kısa bir diyalog, beklenmedik bir zaman geçişi ya da anlatının sonunda beliren tek bir görüntü, kendinden önceki bütün anlatıyı farklılaştırabilir. Mark Turner'ın Bölünmüş Kişilik başlıklı kısa anlatısı da bu yoğunlaştırılmış yapı üzerine kuruludur. Öykü, *Adam mükemmeldi. Kadın büyülenmişti. Ama kafası karışmıştı.* cümleleriyle başlar. İlk bakışta romantik bir karşılaşmanın veya yeni başlayan bir ilişkinin anlatılacağı izlenimi oluşur. Erkek karakter *mükemmel*, kadın ise ondan *büyülenmiş* olarak sunulur. Henüz birkaç cümle içerisinde okurun zihninde güven veren, çekici ve arzu edilen bir erkek imgesi oluşturulmakta bununla birlikte *ama kafası karışmıştı* ifadesi, kurulan bu kusursuz görüntü içinde küçük bir çatlak açmaktadır. Bu çatlak bir yandan idealize edilen diğer yandan bu ideal görüntüyle açıklanamayan bir belirsizliği bünyesinde barındıran erkek üzerinden verilmektedir. Dolayısıyla anlatı daha ilk satırlarında görünür olanla henüz bilinmeyen arasında bir gerilim kurmaya başlar. Erkek karakterin *mükemmel* olarak tanımlanması, onun mutlak anlamda kusursuz olduğunu göstermez. Bu ifade büyük ölçüde kadın karakterin bakışından doğan bir algıyı yansıtmaktadır. Dolayısıyla öykü daha başlangıçta gerçek kişilik ile algılanan kişilik arasındaki mesafeye dikkat çeker.

İnsan, sosyal ilişkiler içerisinde çoğu zaman kendisini bütünüyle ortaya koymaz çeşitli roller, davranış biçimleri ve beklentiler aracılığıyla belirli bir görüntü üretir. Bu görüntü, kişinin toplumla ilişki kurabilmesini sağlayan bir yüz olarak değerlendirilebilir. Jung'un persona kavramı tam da bu noktada karşımıza çıkar. Ona göre "persona, bireyin dış dünyaya karşı genel ruhsal davranış biçimi" (Jung, 2006: 39), bireyin sosyal dünyaya sunduğu ve başkaları tarafından tanınmasını sağlayan yüzdür ancak persona bireyin bütün benliğine eşit şekilde dağılmaz aksine benliğin yalnızca dışarıya dönük, kabul edilebilir ve düzenlenmiş bölümünü temsil eder. "Bir yandan başkaları üzerinde izlenim yaratmak, diğer yandan bireyin gerçek doğasını gizlemek için tasarlanmış bir maske" (Kocabıyık, 2018: 254) olan persona Turner'ın öyküsündeki *mükemmel adam*da okurun karşısına çıkar. Erkek karakterin dışarıdan görünen kimliği güvenilirlik, çekicilik ve uyumluluk üzerine kuruludur. Kadının ona yönelik ilgisi de bu görüntüyü güçlendirir. Böylece erkeğin *mükemmelliği* sadece kendi davranışlarından şekillenmemekte karşısındaki kişinin onu nasıl gördüğünden de üretilmektedir.

Tam da bu noktada çift karakterliliğin önemli bir boyutu olan kişinin iki farklı yönünün bulunması kadar, bu yönlerden hangisinin başkaları tarafından görüldüğü durumu karşımıza çıkar. Erkek karakterin karanlık benliği başlangıçta görünmezdir çünkü ilişki ortamında dolaşıma sokulan kimlik, onun toplumsal ve romantik açıdan kabul edilebilir yüzünü temsil eder. Bu yönüyle öyküdeki çift karakterlilik, birbirinden bağımsız iki kişiliğin nöbetleşe var olmasından çok, görünür kimlik ile gizlenen kimlik arasındaki gerilimi üzerinden şekillenir. "Çift kişilik / kişilik bölünmesi fantastik edebiyatta 'Ben ve Benlik' bağlamında sorunsal bir tema olarak" (Aydın, 2019: 343) işlenmekte çalışmaya konu olan öykünün *Bölünmüş Kişilik* başlığını taşıması, anlatının merkezindeki bu ikiliği daha başlangıçta işaret etmektedir. Metin, klinik bir vaka anlatısından çok, edebiyatın uzun zamandır kullandığı çift benlik, karanlık benlik, öteki ben ve insanın kendi içerisinde taşıdığı karşıt güçler düşüncesine yaslanmaktadır. Edebiyat tarihinde bireyin görünür kişiliği ile bastırılmış veya reddedilmiş yönü arasındaki çatışmanın farklı biçimlerde metin içinde işlendiği görülmektedir. Kimi anlatılarda öteki ben ayrı bir karaktere dönüşürken kimi anlatılarda aynı beden içerisinde saklanan farklı bir yön olarak ortaya çıkar. Turner'ın küçürek öyküsünde ikinci durum söz konusudur. Erkek karakterin gündelik hayatta kabul edilebilir görünen yönü ile dolunayın etkisi altında beliren yırtıcı yönü, aynı varlık içerisinde yan yana bulunmaktadır. Bu yapı, çift karakterlilik kavramının temelinde bulunan özdeşlik ve farklılık paradoksunu gündeme getirir. Öteki, karakterden bütünüyle ayrı değildir fakat karakterin tanınan kimliğiyle de örtüşmez. Başka bir deyişle erkek karakter hem *mükemmel adam*dır hem de anlatının sonunda sezdirilen şiddetin taşıyıcısıdır. Birinin gerçek, diğerinin sahte olduğunu söylemek ise metnin oluşturduğu gerilimi basitleştirebilir. Çünkü "topluma karşı taktığımız bir maske olarak nitelendirebildiğimiz" (Uğurlu, 2022: 1315) persona, kişinin bir parçasıdır ve yırtıcı benlik de onun içerisinde bulunmaktadır. Sorun, bu iki yönün aynı özne içerisinde uzlaştırılamamasından kaynaklanır.

Erkek karakterin çift karakterliliği, iki ayrı beden arasında değil, tek beden içerisinde iki karşıt varoluş biçiminin bulunmasıyla oluşur. Metin içinde "öz süreklilik ve kimlik entegrasyonu eksikliği kahramanların uyumsuz kimliğinin ve bölünmüş benlik duygusunun güçlü bir dilsel işareti" (Stoyanova, 2023: 246) olarak Turner'ın kısa öyküsü içinde hayat bulmaktadır. Öykünün kadın karakteri, erkeğin geçmiş ilişkilerinin neden kısa sürdüğünü merak eder. Bu soru, anlatının kırılma noktalarından biridir. Başlangıçtaki romantik atmosfer içerisinde oldukça sıradan görünebilecek bu merak, anlatının sonunda farklı bir anlam kazanacaktır. İlk okuma sırasında erkeğin geçmiş ilişkilerinin kısa sürmesi; bağlanma korkusu, uyumsuzluk, kişilik özellikleri veya gündelik ilişki sorunlarıyla açıklanabilirken öykünün sonunda meydana gelen ölüm ve kurt uluması, geçmiş ilişkiler hakkındaki bu bilgiyi geriye dönük biçimde dönüştürür. Böylece *kısa süren ilişkiler* ifadesi yalnızca romantik başarısızlıkları değil, tekrar eden bir şiddet örüntüsünü düşündürmeye başlar. Bu noktada öykünün çift karakterlilik temasına döngüsellik eklenmektedir. Erkek karakterdeki karanlık yön tek seferlik bir olay olmayıp geçmişte yaşanmış ve gelecekte yeniden yaşanabilecek bir durumun parçası olarak sezdirilmektedir. Dolunayın kendisi de doğası gereği döngüsel bir göstergedir. Belirli aralıklarla yeniden ortaya çıkan dolunay, karakterin bastırılmış benliğinin de belirli aralıklarla geri dönüşünü simgeler. Böylece doğadaki döngü ile karakterdeki dönüşüm arasında bir paralellik kurulur. Erkek ne kadar uyumlu, çekici ve sıradan bir yaşam sürerse sürsün, belirli bir zamanda bastırılmış olan yeniden ortaya çıkmaktadır. Dolunay bu nedenle yalnızca olayın gerçekleştiği zaman olarak kalmamakta bastırılanın geri dönüşünü düzenleyen simgesel bir eşik olarak da karşımıza çıkmaktadır.

Erkeğin *benim küçük bir sorunum var* biçimindeki açıklaması çift karakterlilik açısından önem taşır. Bu cümlenin anlatı içerisindeki işlevi, gerçeğin büyüklüğü ile onu adlandırmak için kullanılan dilin küçüklüğü arasındaki karşıtlıktan doğar. *Küçük sorun* olarak nitelenen durum, anlatının sonunda ölümle ilişkilendirilen yıkıcı bir niteliğe bürünmektedir. Karakterin kendi içindeki tehlikeyi bu derece sıradan bir ifadeyle anlatması iki farklı düzlemi karşı karşıya getirmektedir. Bunlar gündelik dilin sakinliği ve gizlenen benliğin şiddeti olarak karşımıza çıkar. Bu karşıtlık aynı zamanda erkeğin kendi karanlık yönüyle kurduğu ilişkinin de göstergesi olabilmektedir. "Freud; çift kişilik, kişilik bölünmesi, kendi ikiziyle karşılaşma kısaca ikilik olgusunu fantastik edebiyatta tekinsizlik etkisi yaratan bir öge olarak görür" (Ertem 2013: 282) bu durum metin içindeki karanlık yön üzerinden verilen küçültme eylemini çift karakterliliğin dilsel düzeyde de sürdürüldüğünü görünür kılar. Erkek karakter kendi gerçeğini tamamen açıklamadığı gibi tamamen inkâr etmez hatta *Bir sorunum var* diyerek karanlık yönün varlığını kabul eder fakat *küçük* sözcüğüyle onun gerçek niteliğini örter.

Bu nedenle söz konusu ifade bir tür eşik cümlesidir. Persona ile öteki ben arasındaki sınır bu cümlede kısa süreliğine görünür olur. Okur henüz sorunun niteliğini bilmez fakat anlatı artık kusursuz erkek görüntüsünün arkasında başka bir gerçek bulunduğunu açıkça hissettirmeye başlamıştır. Turner'ın öyküsünde çift karakterlilik, insan ve hayvan karşıtlığı üzerinden somutlaştırılır. Anlatının sonundaki kurt uluması, erkek karakterin kurt adam geleneğiyle ilişkilendirilmesine imkân verir. Kurt adam anlatılarının temelindeki bölünmüş kimlik fikri metin içerisinde okura sunulur. Genellikle onlar "kimliklerini oluştururken "ötekileştirme, benliğe dalma ve eyleme geçme" (Arslan ve Güçlü Demir, 2022: 57) aşamalarından geçirerek kimlik kazanma eyleminin gerçekleşmesini sağlamakta" bu durumun görünürlüğü de metin içinde karşımıza çıkmaktadır. İnsan bedeni ve bilinci kimi zaman hayvani bir varlığa dönüşmekte yabanıl yanlar gün yüzüne çıkmaktadır. Medeniyetin kurallarıyla yaşayan toplumsal özne, yerini içgüdüsel, saldırgan ve kontrol edilemeyen bir varlığa bırakmaktadır. Bu nedenle kurt adam figürü, edebiyatta çift karakterliliğin en güçlü simgelerinden biri olarak yer yer karşımıza çıkar. İnsanın içerisinde bastırılmış olarak bulunduğu farz edilen yabanıl yön, fiziksel bir dönüşüm aracılığıyla görünür hale gelir. Öyküde bu dönüşüm doğrudan anlatılmamakta erkek karakterin bedensel olarak kurda dönüştüğü açıkça söylenmediği gibi cinayet anı da gösterilmemektedir ancak dolunay, parçalanmış ya da kanlar içerisindeki ceset ve uzaktan gelen kurt sesi bir araya geldiğinde okur eksik bırakılmış olay zincirini kendisi kurabilecek bir mertebeye erişir. Bu anlatısal tercih, küçürek öykünün temel yapısıyla doğrudan ilişkilidir. Uzun bir anlatıda sayfalar boyunca aktarılabilecek dönüşüm ve saldırı sahnesi burada bütünüyle çıkarılmış metin, neden-sonuç ilişkisini açıkça anlatmak yerine iki sahne arasındaki boşluğu okurun zihnine yerleştirmiştir. "Küçürek öykü çok az sözcükle bir durumun veya anın özünü hızla yakalayıp ortaya koyan bir anlatı, bir anlık görüntü veya tek bir kareymiş gibi kısa olsa da sahip olduğu küçük sınırlar içerisinde büyük bir özgürlük barındıran öykülerdir" (Varışoğlu ve Şahin, 2026: 4). Bu yönü küçürek öyküye anlatısal bir eksilti ve düşünsel bir derya açmaktadır. Anlatısal eksilti bu bağlamda yalnızca metni kısaltan biçimsel bir yöntem olmamakta yine eksilti aynı zamanda öykünün anlam üretme mekanizmasının da merkezine yerleşmektedir.

Erkek karakterin sözünden, doğrudan dedektifin genç kadının cesedine baktığı ana geçilmesi anlatı zamanında büyük bir boşluğu da beraberinde getirmektedir. Bu boşlukta ne gerçekleştiği söylenmemekte okur, kendisine sunulan sınırlı verileri birbirine bağlamak zorunda kalmaktadır. Dolunay, kanlı beden ve kurt sesi birleşerek eksik anlatının zihinsel olarak tamamlanmasını metin içinde sağlar. Böylece anlatı, kendi olay örgüsünün önemli bir bölümünü okura yazdırır. Bu özellik, Wolfgang Iser'in metindeki boşlukların okur tarafından doldurulmasına ilişkin yaklaşımıyla birlikte düşünülebilir. Ona göre "metnin yapılandırılmış boşlukları, okuyucu tarafından metin tarafından belirlenen terimler üzerinde gerçekleştirilecek fikir oluşturma sürecini teşvik eder" (Iser, 1978: 169). Edebi metin, her şeyi açıkça söylemek yerine birtakım boşluklar bıraktığında, okuma eylemi daha etkin bir hal alır. Böylece okur yalnızca anlatılanları kabul eden pasif bir alıcı olmaktan çıkar ve anlatının parçaları arasındaki bağlantıyı kuran kişiye dönüşür. Turner'ın öyküsünde de esas şiddet sahnesinin anlatılmaması okuru olayın zihinsel kurucusu haline getirir. Bu nedenle metnin kısalığı anlam eksikliğine yol açmaz tam tersine eksiklik anlam üretir. Burada geciktirilmiş anlam kavramı özellikle önem kazanmaktadır. Öykünün ilk cümlelerinde yer alan ifadelerin gerçek işlevi ancak metnin sonuna ulaşıldığında anlaşılır. Başlangıçta olumlu çağrışımlar taşıyan *mükemmel* sözcüğü, finalden sonra ironik bir değer kazanır. Kadının *büyülenmiş* olması, ilk aşamada romantik etkilenmeyi anlatırken son bölümdeki fantastik atmosfer nedeniyle daha karanlık ve tekinsiz çağrışımlara açılır. Geçmiş ilişkilerin kısalığı önce sıradan bir ilişki sorunu olarak karşımıza çıkar daha sonra başka kadınların da benzer bir son yaşamış olabileceği düşüncesini doğurur. *Küçük sorun* ise bütün anlatının merkezindeki ölümcül gerçeğin üstünü örten bir ifadeye dönüşür. Dolayısıyla öykünün anlamı doğrusal biçimde kurulmaz. Okur ilk cümleden son cümleye kadar sürekli yeni bilgiler eklemekle yetinmez finalde aldığı bilgiyle başlangıca zihinsel olarak geri döner. Bu geriye dönüş, önceki ifadelerin anlamını değiştirir. Böylece anlatının sonunda meydana gelen şey yalnızca bir sürpriz değildir. Sürpriz son bütün metni yeniden okumayı gerektiren anlamsal bir dönüşüme yol açmaktadır. Geciktirilmiş anlam tam da bu noktada ortaya çıkar. Küçürek öykü türünde bu teknik oldukça etkilidir. Çünkü metnin kısa olması, okurun başlangıca zihinsel olarak geri dönmesini kolaylaştırır. Bir romanın yüzlerce sayfa önce sunduğu ayrıntının yeniden değerlendirilmesiyle küçürek öyküde birkaç cümle önce sunulan ayrıntının yeniden değerlendirilmesi aynı değildir. Küçürek öykü, bütün yapısını okurun belleğinde aynı anda tutabileceği kadar küçük bir alana sığdırır. Böylece finalde verilen bir gösterge, metnin tümünü tek seferde dönüştürebilir.

Turner'ın anlatısında kurt ulumasının yaptığı tam olarak budur. Son cümle, kendisinden önce gelen bütün cümlelerle yeni ilişkiler kurar ve onların anlamını değiştirir. Metin içindeki kurt sesi varlık ile yokluk arasında bir konuma sahiptir. Kurt görülmez yalnızca sesi duyulur. Bu durum erkek karakterin öteki beninin temsil biçimiyle uyumludur. Bu "varoluşsal olanaklılığın belirlediği kendi oluş süreci özgürlük, farkındalık, seçim ve sorumluluk bağdaşıklığında 'kendilik bilinci' boyutuyla" (Deveci, 2012: 149) Turner öyküsü içinde karşımıza çıkar. Karanlık benlik, hiçbir zaman tamamen görünür olmaz. Okur ne dönüşümü görür ne saldırıyı ne de saldırganı cinayet anında gözlemler. Yalnızca sonuç ve ses vardır. Böylece öteki ben, doğrudan gösterilmek yerine izleri aracılığıyla kurulur. Bu anlatım biçimi, karanlık benliği daha tekinsiz hale getirir; çünkü görünmeyen varlık okurun zihninde daha geniş bir alan kaplar. Freud'un "korku yaratan şeylerin eskiden beri bilinen ve yabancı olmayan bir şeye geri uzanan türü" (Freud, 1999: 326) olarak tanımladığı *tekinsiz* kavramıyla birlikte düşünüldüğünde, öykünün yarattığı rahatsızlığın yalnızca fantastik bir canavar figüründen kaynaklanmadığı görülür. Tekinsiz olan, bütünüyle yabancı olan değil, bir zamanlar tanıdık veya güvenli görünen şeyin farklı bir yüzle geri dönmesidir. Turner'ın öyküsündeki erkek karakter tam da bu nedenle korkutucudur. Karakter başlangıçta okura yabancı ve tehditkâr bir canavar olarak tanıtılmış olsaydı, anlatının etkisi büyük ölçüde azalırdı. Asıl korku, güvenilir ve *mükemmel* olarak görünen kişinin aynı zamanda ölümcül bir tehdidi içerisinde taşımasıdır. Bu açıdan çift karakterlilik, öyküde korkunun temel üretim mekanizmasıdır. Karakter ikili kutupları bünyesinde taşımakta bunlar da karşımıza uygar/yabanıl, insan/hayvan, sevgi/şiddet, yakınlık/tehdit, güven/korku şeklinde çıkmaktadır. Bu ikili karşıtlıklar yalnızca karakteri açıklamakla kalmayıp metnin bütün semantik yapısını da biçimlendirmektedir. Anlatının ilk bölümü yakınlaşma üzerine kurulurken ikinci bölümü ölüm üzerine kuruludur. Birinci kısımda ilişkinin olasılığı ikinci kısımda ise ilişkinin yıkıcı sonucu vardır. Birinci kısımda canlı ve hareket halindeki iki insan bulunurken ikinci kısımda kadın artık bir cesettir ve erkek görünmez olmuştur. Böylece karakterdeki bölünme, anlatının yapısal bölünmesine de yansımaktadır.

Metnin romantik bir anlatı gibi başlayıp gotik ve polisiye bir anlatıya dönüşmesi ikircikli yapının bir başka görünümünü bize verir. Başlangıçta kadın ve erkek arasındaki konuşma, romantik ilişki anlatılarının tanıdık kalıplarını çağrıştırır. Kadın erkeğin geçmişi hakkında soru sormakta, erkek kişisel bir sırrını açıklamaya hazırlanmakta ve iki kişi yürürken aralarında yakınlaşma gerçekleşmektedir fakat anlatı aniden bir suç mahalline geçer. Dedektif, kanlar içindeki bir cesede bakmaktadır. Böylece romantik anlatının mekânı ve tonu parçalanarak yerine polisiye ve gotik bir atmosfer geçer. Türsel değişim de tıpkı erkek karakterin dönüşümü gibi ani ve keskindir. Bu açıdan *bölünmüşlük* hem karakter psikolojisinin hem de anlatının kendisinin temel ilkesi haline gelir. Metin taşıdığı anlatı kimlikleri karşımıza romantizm ve korku düzleminde çıkar. Bunlardan ilki ikinciyi gizler. Bu bakımdan metin ile erkek karakter arasında biçimsel bir benzerlik bulunduğu söylenebilir. Erkek karakter nasıl "kişiliğin görünen yüzünü temsil eden güvenilir bir persona" (Storr, 2006: 85) arkasında yırtıcı benliğini saklıyorsa anlatı da romantik bir başlangıcın arkasında korku öyküsünü saklamaktadır.

Okur hem karakter hem de metin tarafından aynı anda yanıltılır. Böylece çift karakterlilik teması içerikle sınırlı kalmaz anlatım biçimine dönüşür. *Adam* ve *kadın* biçimindeki adlandırma, anlatının belirli iki kişiden çok insan ilişkilerinde görünen ve gizlenen kimlikler üzerine kurulmasını mümkün kılar. Bununla birlikte finalde kadının *genç kız* ve ardından *ceset* olarak görülmesi, karakterin özne konumundan nesne konumuna geçişini de gösterir. Anlatının başında soru soran, merak eden ve hareket eden kadın, sonunda yalnızca dedektifin baktığı bir bedene dönüşmüştür. Bu dönüşüm, erkeğin çift karakterliliğinin sonuçlarını görünür kılar. Erkek karakterdeki karanlık yön yalnızca onun kendi iç dünyasıyla ilgili bir problem olmayıp başka bir kişinin yaşamını ortadan kaldıran somut bir şiddete de dönüşmektedir. Dolayısıyla metin, çift benlik temasını yalnızca bireyin kendi içinde yaşadığı soyut bir çatışma olarak ele almaz. Bastırılmış öteki, dış dünyaya yöneldiği anda yıkıcı sonuç üretir. Bu yönüyle *gölge* kavramı da anlatının yorumlanmasında önem kazanır. Jung'un psikolojisinde gölge, kişinin bilinçli benlik tasarımına dahil etmek istemediği, bastırdığı veya kendisiyle özdeşleştirmediği özellikleri ifade eder. "Persona arketipi kişiliğin toplum tarafından kabul edilen özelliklerini kendinde toplarken topluma uygun olmayan yönlerini bastırır ve bilinç dışında kişiliğin karanlık tarafı olan gölge arketipi ortaya çıkar" (Stevens, 2014: 100) bu gölge her zaman yalnızca kötülüğe karşılık gelmese de bireyin kabul etmekte zorlandığı yönleri barındırır. Turner'ın erkek karakterinde ise gölge, saldırganlık ve yırtıcılıkla belirginleşmektedir. *Mükemmel* persona ile ölümcül gölge arasındaki mesafe büyüdükçe karakterin çift yapısı daha belirgin hale gelir.

Gündelik yaşamda görünmez olan gölgeyi dolunay yüzeye çıkaran bir eşik işlevi görür. Dolunayın simgesel anlamı bu nedenle yalnızca kurt adam mitolojisine yapılan kültürel bir gönderme ile sınırlı değildir. Ayın karanlıkla, geceyle, değişimle ve döngüsellikle ilişkilendirilen yapısı, karakterin kimliğindeki geçişi görünür hale getirir. Dolunay, gecenin en fazla aydınlandığı zaman olmasına rağmen öyküde paradoksal biçimde en karanlık benlik bu aydınlık altında ortaya çıkmaktadır. Böylece ışık ve karanlık arasındaki geleneksel karşıtlık tersine çevrilir. Gündelik yaşamın aydınlık dünyasında saklı kalan karanlık taraf, gecenin dolunay ışığında metin içinde görünü hale gelmektedir. Ay burada karanlığı ortadan kaldırmaktan ziyade gizliyi açığa çıkaran bir ışık kaynağı formundadır.

Metin içindeki öteki ben, karakterin dışından gelen bir varlık değildir. Dolunay onu yaratmaktan çok görünür kılmayı yeğlemektedir. Bu noktada "gölge, personanın bastırdığı yönleri ortaya çıkararak personanın taktığı maskeyi düşürür" (Yıldırım Sağlam, 2022: 262). Başka bir ifadeyle dönüşümün kaynağı yalnızca dışsal koşul olmamakta aksine zaten öznenin içerisinde bulunan gölgelenmiş potansiyel olarak vermektedir. Bu nedenle kurt figürü karaktere eklenen yabancı bir unsurdan çok, onun bastırılmış yönünün bedenleşmiş karşılığı olarak okunabilir. Erkek karakter gündelik yaşamda insani ve toplumsal roller içerisinde hareket ederken öteki ben ortaya çıktığında denetim, dil ve sosyal davranış ortadan kalkar yerini saldırıya bırakır. Bu ikiliği mutlak bir insan/hayvan karşıtlığı şeklinde değerlendirmek yerine hayvan figürünün insanın kendi içerisinde bastırdığı saldırganlık için bir metafor oluşturduğu söylenebilir. Bu bağlamda öykü, canavarlığın dışarıdan gelen bir tehdit olmadığı düşüncesini öne çıkarır. Canavar, toplumun dışındaki bilinmeyen bir yaratık olmamakta güvenilir görünen kişinin içinde taşınmaktadır. Böyle bir yaklaşım anlatının korku etkisini belirgin biçimde artırmaktadır. Okur için tehlikeli olan yalnızca kurt değildir kurdun insan yüzüyle dolaşabilmesidir. Dolayısıyla *mükemmel adam* ile *yırtıcı öteki* birbirini dışlamaz tam tersine korku, bu iki kimliğin aynı bedende bulunabilmesinden doğar. Bu durum çift karakterliliğin etik boyutunu da gündeme getirir. Erkek karakter karanlık yönünün farkındalığını taşımaktadır. "Ben ve ben'e benzemeyen öteki'den oluşan ikili kahramanlar ikiz kahramanların farklılaşmasıyla ortaya çıkan eşruhlar gibi gölge arketipine bağlıdırlar" (Nakıboğlu, 2014: 84). *Küçük bir sorunum var* ifadesi, en azından onun kendi durumuna ilişkin belli bir bilgi taşıdığını düşündürür. Bu farkındalık, anlatının sorumluluk meselesini daha karmaşık hale getirir. Eğer karakter dönüşümünü biliyorsa geçmiş ilişkilerinin kısa sürmesinin nedenini de bilmesi mümkündür. Buna rağmen yeni bir ilişki kurmaktadır. Öykü bu noktada ayrıntıya girmez ancak eksilti, okurun ahlaki sorular üretmesine imkân verir.

Metin içinde kurt ulumasının uzaklardan gelmesi bilinçli bir belirsizlik yaratır. Sesin kaynağının erkek olduğu açıkça belirtilmez. Dolayısıyla öykü, fantastik açıklamayı güçlü biçimde sezdirirken onu mutlaklaştırmaz. Okur bağlantıyı kendi kurar, bağlantılar arasındaki "boşluklar okurun ilgi ve merakını artırır ve okurun metnin anlam kazanmasına dinamik şekilde katılımını sağlar" (Rimmon, 2002, 127). Metin içindeki okuru metne dahil eden bu belirsizlik, anlatıyı yalnızca bir kurt adam öyküsü olmaktan çıkarıp metaforik okumaya da açık hale getirir. Erkek gerçekten fiziksel olarak bir kurda dönüşmüş olabilir fakat kurt aynı zamanda onun şiddete eğilimli karanlık benliğinin simgesi de olabilir. İki okuma birbirini dışlamak zorunda değildir. Fantastik düzeyde gerçekleşen dönüşüm, psikolojik düzeyde benliğin parçalanmasını temsil edebilir. Küçürek öykü açıklama alanını daralttığı için kesin anlamdan ziyade yoğun çağrışım üretir. Turner'ın anlatısı, okura kurt adam mitini çağrıştıracak kadar veri verir fakat bu miti ayrıntılı bir fantastik evrene dönüştürmez. Aynı şekilde psikolojik bölünmeye ilişkin işaretler sunar fakat karakterin iç dünyasını açıklamaz. Böylece anlatı iki anlam düzeyi arasında tutulur: görünür olay ve onun sembolik karşılığı. Bu ikircikli yapı geciktirilmiş anlamla birleştiğinde metnin temel estetik etkisini oluşturur. Okur başlangıçta romantik bir öykü okumakta olduğunu düşünür. Sonra karakterin bir sırrı bulunduğu anlaşılır. Ardından metin ani biçimde ölüm sahnesine geçer ve son olarak kurt sesi duyulur. Her yeni bilgi, önceki bilgileri ortadan kaldırmadan onların anlamını değiştirir. Bu nedenle anlatının sonunda okurun sahip olduğu metin, başlangıçta okuduğunu düşündüğü metinden farklıdır. Sözcükler değişmemiştir fakat anlamları değişmiştir. Geciktirilmiş anlamın gücü burada ortaya çıkar. Metin içinde verilen "geciktirim, olayların devamı için beklenti yaratır ve olayların nasıl devam edeceğine dair belirsizlik oluşturur" (Büyükkavas Kuran, 2025: 661). Anlam metnin belirli bir noktasında gizlenmiş hazır bir nesne olmaktan ziyade okuma süreci içerisinde sürekli yeniden kurulur. Son cümle başlangıç cümlesini değiştirir, başlangıç cümlesi de finalin etkisini güçlendirir. *Mükemmel adam* ifadesi olmasaydı kurtla ilişkili final bu kadar güçlü bir karşıtlık yaratmazdı aynı şekilde kurt uluması olmasaydı *mükemmel* sözcüğü ironik bir niteliğe kavuşmazdı.

Dolayısıyla metnin parçaları arasında çift yönlü bir anlam ilişkisi vardır. Bu geriye dönük anlamlandırma, küçürek öykünün zaman yapısını da etkiler. Anlatı kronolojik olarak ilerlerken okuma deneyimi dairesel hale gelir. Okur sona ulaştığında başlangıca geri döner ve önceki ayrıntıları yeniden değerlendirir. Bu durum dolunayın döngüsel niteliğiyle de simgesel olarak örtüşmektedir. Dolunay nasıl belirli aralıklarla geri dönüyorsa okurun zihni de finalden sonra başlangıca geri döner. Böylece içerikteki döngüsellik ile okuma sürecindeki döngüsellik arasında dikkat çekici bir paralellik oluşur.

Metnin sonundaki dedektif figürü anlatının anlam dünyasında dikkate değer bir işleve sahiptir. Dedektifin ortaya çıkmasıyla anlatı bir anda romantik yakınlaşmadan suç soruşturması atmosferine geçer. Dedektif geçmişte gerçekleşmiş olayın ardından gelen rasyonel dünyayı temsil eder ancak onun varlığı cinayeti açıklamaya yetmez. Dedektif yalnızca sonucu görmektedir tıpkı okur gibi olayın kendisine tanıklık etmemiştir. Bu açıdan dedektif ile okur arasında bir benzerlik kurulabilir. Her ikisi de birtakım izlerden hareketle ne olduğunu anlamaya çalışır. Ceset ve çevresel göstergeler dedektif için nasıl kanıtsa, anlatının cümleleri de okur için aynı işlevi görür. Okur, dedektiften farklı olarak kurt ulumasının anlatısal değerini bilir. Bu ses, rasyonel polisiye açıklamanın sınırlarını aşan fantastik bir ihtimali metne sokar. Böylece öykü bir taraftan suçun ardından gelen araştırma dünyasını çağrıştırırken diğer taraftan rasyonel açıklamanın ötesine geçen bir gerçeklik kurar. Çift karakterlilik bu kez türler arasındaki sınırın bulanıklaşması biçiminde ortaya çıkar. Bu yönüyle anlatı hem polisiye hem gotik hem gündelik hem de fantastiktir. Başlangıç ve son arasındaki karşıtlık, kadının erkeğe yönelik algısının parçalanmasıyla da ilişkilendirilebilir. Kadın, karşısındaki kişiyi onun görünen davranışları üzerinden değerlendirir ancak ilişkinin kısa süresi içerisinde bu görüntünün ardında bütünüyle farklı bir kimlik bulunduğu ortaya çıkar. Bu durum insan ilişkilerinde *öteki*nin tam olarak bilinememesi düşüncesine açılır. Her yakınlık, karşıdaki kişinin iç dünyasına bütünüyle ulaşmayı mümkün kılmaz. İnsan, diğerinin kendisine sunduğu yüzü görür ve çoğu zaman bu yüzü bütün kişilikle özdeşleştirir. Turner'ın öyküsü bu gündelik durumu fantastik düzeye taşıyarak radikalleştirir. Kadının tanıdığını düşündüğü erkek ile gerçekte karşılaştığı varlık arasındaki mesafe ölümcül boyuttadır. Bu bakımdan *büyülenme* sözcüğü de önem taşır. Romantik bağlamda büyülenme, kişinin karşısındaki insanı aşırı ölçüde etkileyici bulmasını ifade eder ancak büyülenme aynı zamanda gerçekliğin sağlıklı biçimde değerlendirilmesini engelleyen bir etkilenme biçimini de çağrıştırabilir. Kadının erkek karşısındaki büyülenmişliği, onun *mükemmel* persona ile gerçek benlik arasındaki farkı görememesine katkıda bulunmaktadır. Finalde ortaya çıkan fantastik çağrışım ise *büyülenme* sözcüğüne üçüncü bir anlam katmanı ekler. Böylece sıradan bir romantik sözcük, metnin sonunda doğaüstü atmosfere bağlanan çok anlamlı bir göstergeye dönüşür.

Metin karakterlerin geçmişini, fiziksel özelliklerini, ilişkinin ayrıntılarını veya saldırının nasıl gerçekleştiğini anlatmaz. Buna rağmen birkaç sözcük geniş çağrışım alanları oluşturur. *Mükemmel, büyülenmiş, kısa, sorun, dolunay, kan* ve *kurt* kelimelerinin her biri anlatının farklı bir katmanını taşır. Küçürek öykünün yoğunluğu, sözcüklerin yalnızca sözlük anlamlarıyla değil, birbirleriyle kurdukları ilişkiler sayesinde ortaya çıkar. Yine "küçürek öykünün birdenbirelik (sudden) niteliği karanlıkta çakan bir şimşek gibi açıklık/yalınlık ve çıplaklık içinde ansızın yakaladığı kişiyi" (Korkmaz ve Deveci, 2017: 36, 37) kimi zaman sezdirir kimi zaman da onu saklanılmaz kılar. Özellikle dolunay ve kurt arasındaki ilişki, metnin çok az sözcükle büyük bir anlatıyı çağırabilmesini sağlar. Yazarın kurt adam mitini ayrıntılı biçimde açıklamasına gerek yoktur çünkü okurun kültürel belleği küçürek öyküdeki bu boşluğu doldurmaktadır. Dolunayın ardından gelen kurt uluması, yüzyıllardır anlatılan dönüşüm hikâyelerini çağrıştırır. Böylece küçürek öykü hem kendi cümlelerinden hem de okurun daha önce karşılaştığı kültürel anlatılardan beslenir. Metnin hacmi küçüldükçe metin dışı çağrışımların önemi artmasına rağmen öyküyü yalnızca bilinen kurt adam mitinin kısa bir yeniden anlatımı şeklinde değerlendirmek yeterli değildir. Anlatının özgün yönlerinden biri, dönüşümün kendisinden ziyade dönüşümün ilişkisel sonucunu merkeze almasıdır. Burada asıl mesele bir insanın fiziksel olarak kurda dönüşmesinden çok, bir kişinin sevilebilir ve güvenilebilir görüntüsü ile ölümcül yönünün aynı bedende bulunmasıdır. Kurt adam motifi böylece çift karakterliliğin görünür simgesine dönüşür. Bu noktada *öteki ben* kavramı, metnin merkezindeki çatışmayı açıklamak için elverişlidir. "Eş benlikte gölge ve yansıma, ben'in bağımsız bir gözle görülür bölünmesi olarak karşımıza" (Rank, 2016: 35) çıkmakta böylece öteki ben, kişinin bilinçli olarak kurduğu kimlik tasarımının dışına attığı ancak yine de kendisine ait olan yönü temsil etmektedir. Erkek karakterin yırtıcı tarafı, onun toplumsal dünyada göstermek istemediği benlik olmasına rağmen bu yön bütünüyle ortadan kalkmamış hatta bastırılmış olmasına rağmen belirli koşullarda geri dönmektedir. Böylece öteki ben, yok edilmiş değil ertelenmiş bir benliktir.

Çalışmaya konu olan metin içinde geciktirilmiş anlam ile bastırılmış benlik arasında yapısal bir benzerlik bulunmaktadır. Karakterin öteki yüzü nasıl anlatının sonunda ortaya çıkıyorsa metnin gerçek anlamı da aynı anda ortaya çıkar. Başka bir ifadeyle hem karakter hem anlam gizlenmiş ve ertelenmiştir. Öykünün biçimi, anlattığı psikolojik çatışmayı tekrarlar. Erkek karakter karanlık yönünü saklar metin de gerçek türünü ve anlamını saklar. Dolunay karakterin öteki benini görünür kılarken final metnin öteki anlamını görünür kılar. Bu açıdan *Bölünmüş Kişilik*, içerik ile biçimin birbirini tamamladığı bir küçürek öyküdür. Çift karakterlilik yalnızca anlatılan bir tema olmamakta anlatım biçiminin kendisi de çift yapılı bir mekanizma olarak karşımıza çıkmaktadır. Metnin ilk yüzü romantik, ikinci yüzü korkutucudur. İlk okuma düzeyi gündelik ikinci okuma düzeyi simgeseldir. İlk anlam görünür, ikinci anlam geciktirilmiştir. Böylece öykünün biçimsel örgütlenmesi karakterin iki yüzlü yapısının estetik karşılığı haline gelir. Anlatının son görüntüsü, bu yapının bütün unsurlarını bir araya getirir. Genç kadının kanlar içerisindeki bedeni, dolunay ve uzaktan duyulan kurt sesi arasında doğrudan açıklanmayan fakat güçlü biçimde kurulan bir ilişki vardır. Ceset, dönüşümün sonucunu; dolunay, dönüşümün zamanını; kurt uluması ise dönüşümü gerçekleştiren karanlık benliği temsil eder. Erkek karakter fiziksel olarak sahnede yoktur fakat tam da bu yokluk içerisinde en güçlü varlığına ulaşır. Okur onu görmediği hâlde anlatının bütün göstergelerini onun etrafında birleştirir. Bu nedenle öykünün korkusu görsel şiddetin ayrıntılarından ziyade çıkarımın kendisinden doğar. Okur kendisine açıkça söylenmeyen şeyi anladığı anda anlatı tamamlanır. Bu tamamlanma aynı zamanda geriye dönük bir fark ediştir. Kadının kafasının neden karıştığı, erkeğin ilişkilerinin neden kısa sürdüğü, *küçük sorun*un ne olduğu ve dolunayın neden özellikle belirtildiği birbirine bağlanır. Metin, son cümlesiyle çözülmekten çok yeniden kurulmaktadır.

SONUÇ

Mark Turner'ın *Bölünmüş Kişilik* adlı küçürek öyküsü, çift karakterlilik temasını olağan ile olağanüstü, insan ile hayvan, sevgi ile şiddet, persona ile gölge ve görünüş ile gerçeklik arasındaki karşıtlıklar üzerinden yoğunlaştırmaktadır. Erkek karakterin başlangıçta *mükemmel* olarak algılanan yüzü, toplumsal ve romantik personasını temsil ederken dolunayla ilişkilendirilen yırtıcı yönü, bastırılmış öteki benin açığa çıkışına dönüşmektedir. Bu iki yön birbirinden bütünüyle bağımsız olmamakta tam tersine aynı kişinin farklı yüzleri olarak metnin temel gerilimini oluşturmaktadır. Öykünün asıl başarısı, bu çift karakterliliği yalnızca tematik düzeyde bırakmamasıdır. Anlatının kendisi de çift katmanlıdır. Romantik bir karşılaşma biçiminde başlayan metin, finalde gotik ve polisiye bir anlatıya dönüşür. Karakter nasıl görünen kimliğinin arkasında başka bir benlik taşıyorsa anlatı da ilk görünümünün altında başka bir türsel ve anlamsal kimlik taşımaktadır. Bu nedenle başlıktaki *bölünmüşlük*, hem karaktere hem de metne uygulanabilecek bir kavram haline gelir. Geciktirilmiş anlam bu yapının tamamlayıcı unsurudur. Metindeki göstergelerin gerçek değeri ilk karşılaşıldıkları anda bütünüyle anlaşılmaz. Finalde ortaya çıkan dolunay ve kurt imgesi, başlangıçtaki bütün ayrıntıları yeniden düzenler. Böylece okuma eylemi doğrusal olmaktan çıkar ve geriye dönük bir yeniden anlamlandırma sürecine dönüşür. Okur, metnin sonunda başlangıca geri dönerek önceki cümlelerin farklı anlamlarını keşfeder. Turner'ın anlatısında korkunun kaynağı tek başına doğaüstü dönüşüm değildir. Daha derindeki korku, yırtıcı benliğin uzun süre güvenilir, sevilebilir ve hatta *mükemmel* bir insan görüntüsü altında varlığını sürdürebilmesidir. Canavar dışarıdan gelmemekte tanıdık olanın içerisinden çıkmaktadır. Dolunay da bu nedenle yeni bir kişilik yaratmaz gündelik yaşamın örttüğü öteki benin üzerindeki perdeyi kaldırır. Öykünün sonunda duyulan kurt uluması sadece bir hayvan sesi olmamakta görünür benliğin gerisinde sessizce bekleyen ve uygun anda ortaya çıkan karanlık tarafın da sesini yansıtmaktadır. Küçürek öykünün yoğunlaştırılmış anlatım imkanları sayesinde birkaç cümle içerisinde kurulan bu yapı, insanın kendi içerisinde taşıdığı karşıtlıkları, kişiliğin görünen ve görünmeyen katmanlarını ve anlamın ancak anlatının sonunda tamamlanan doğasını da etkili biçimde ortaya koymaktadır.

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GAFLETTEN MARİFETE: ŞEYH GÂLİB DİVANI'NDA UYKU METAFORU

FROM HEEDLESSNESS TO GNOSIS: THE SLEEP METAPHOR IN THE DĪVĀN OF SHAYKH GĀLIB

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ÖZET

Şeyh Gâlib, (ö. 1213/1799) Anadolu sahası klasik Türk edebiyatının on sekizinci yüzyılda yetiştirdiği son ve önemli şairlerinden biridir. Tekke edebiyatının belki son temsilcilerinden sayılmasının yanında mesnevi türündeki "Hüsn ü Aşk" adlı eseriyle, Divan edebiyatına ve mesnevi türüne hem yeni bir açılım ve tarz getirmiş hem de kendine has orijinal bir eser ortaya koyarak büyük katkılarda bulunmuş bir şairdir. Şeyh Gâlib, Divan şiirinde kendine özgü üslubu, anlayışı ve Tasavvufi düşüncesiyle özel bir yere sahiptir. Sebk-i Hindî üslubunun ses özellikleri, ince ve karmaşık hayalleriyle Tasavvufî umdelerin derin anlamlarını sentezleyerek hususi bir tarz ortaya koymaya çalışmıştır. Onun, divanının yanında "Hüsn ü Aşk" adlı eseri, Hint üslubuyla Tasavvuf anlayışının ince hayallerinin ve karmaşık duygularının, tecessüm etmiş hali gibidir. Tüm bu özelliklerinin yanında dilinin de ağır olması, Şeyh Gâlib'i Divan edebiyatında Nef'î, Nedim ve Nâilî gibi önemli bir mevkie yükseltmekle birlikte onun, anlaşılması zor bir şair olduğunu da göstermektedir. Şu kadar var ki Yenikapı Mevlevihanesi civarında bu âleme gözünü açan Şeyh Gâlib, belli bir ilim ve Tasavvuf muhitinde yetişmiş ve ölene kadar bu muhitte hayat sürmüştür. Dolayısıyla o sadece bir şair değildir; onun manzumelerini anlamak ve açıklayabilmek için onun neşet ettiği camianın ilmine ve sanatına belli ölçüde vakıf olmak gerekir.

Bu çalışmada, Şey Gâlib'in divanı esas alınmak suretiyle, "Uyku Metaforu" ile ilgili beyitler seçilmiş, bu beyitlerdeki "Uyku" kavramı ele alınarak edebî, Tasavvufî, teoloji ve diğer bakımlardan incelenerek değerlendirmelerde bulunulmuştur. Öncelikle, "Uyku Metaforu"nun literatürdeki yeri araştırılmış, daha sonra metin merkezli olarak Şeyh Gâlib'in divanında, bu metaforla ilgili beyitler tespit edilerek bu beyitler, anlatım biçimi, mazmunlar, Tasavvufi sembol ve kavramları anlamlandırma ve edebi sanatlar bakımından incelenmiştir.

Anahtar kelimeler: Şeyh Galib, İnsan, uyku, gaflet, marifet, Tasavvuf

ABSTRACT

Shaykh Gālib (d. 1213/1799) is regarded as one of the last and most distinguished poets produced by the Anatolian tradition of Classical Turkish literature in the eighteenth century. Considered among the final representatives of Tekke (Sufi lodge) literature, he made a significant contribution to both Divan poetry and the mathnawī tradition through his celebrated work Hüsn ü Aşk (Beauty and Love), introducing an innovative poetic style while producing a highly original masterpiece. Owing to his distinctive poetic voice, aesthetic vision, and Sufi thought, Shaykh Gālib occupies a unique position within the Divan literary tradition. By combining the phonetic qualities, subtle imagery, and intricate imagination of the Sebk-i Hindī (Indian Style) with the profound meanings of Sufi principles, he developed a highly original poetic style. Alongside his Dīvān, Hüsn ü Aşk may be regarded as the embodiment of the refined imagination and complex emotional world created through the synthesis of the Indian Style and Sufi thought. The density and complexity of his language elevate Shaykh Gālib to a position comparable with major Divan poets such as Nef'î, Nedim, and Nâilî, while also making him one of the most challenging poets to interpret. Born in the vicinity of the Yenikapı Mevlevi Lodge, Shaykh Gālib was raised within an intellectual and Sufi milieu and remained in that environment throughout his life. Consequently, he should be understood not merely as a poet but also as a representative of a particular intellectual and spiritual tradition. Interpreting his poetry therefore requires a substantial familiarity with the scholarly, artistic, and mystical culture in which he was nurtured.

This study examines the metaphor of sleep in Shaykh Gālib's Dīvān. Couplets related to the sleep metaphor were identified and analyzed from literary, Sufi, theological, and other relevant perspectives. The study first investigates the place of the sleep metaphor within the existing literature and then, through a text-centered approach, identifies and analyzes the relevant couplets in the Dīvān.

These couplets are examined with particular attention to their modes of expression, conventional poetic motifs (mazmūns), the interpretation of Sufi symbols and concepts, and the literary devices employed.
Keywords: Shaykh Gālib, human being, sleep, heedlessness, gnosis (maʿrifa), Sufism.

GİRİŞ

Uyku, öncelikle insanların da içinde bulunduğu canlılar âlemine mahsus bir özelliktir. Literatürdeki tarifine göre uyku; "Bilincin değiştiği ve duyusal etkinliğin belirli bir dereceye kadar azaldığı, bilinçli zihinsel etkinliğin durduğu bir haldir. Uykuda kas ve çevre ile etkileşim azalır. Uyku, uyaranlara tepki verme yeteneği açısından uyanıklıktan farklı olsa da aktif beyin kalıplarını içerir ve bu da onu koma veya bilinç bozukluklarından daha duyarlı yapar"[46]

Uyku, canlıların hayatlarını daha sağlıklı ve mükemmel sürdürebilmeleri için önemli bir zorunluluktur ve hayatın başlangıcından itibaren mevcut olan bir durumdur. Uykuyla birlikte canlılar bağışıklık, sinir, iskelet ve kas gibi bedensel sistemlerin birçoğunu revize etme imkânını bulurlar. Uykunun, canlıların tekâmül ve gelişim sürecinde de korunmuş bir davranış olduğu ifade edilmektedir[47] ve mazisi yüz milyonlarca yıl öteye kadar götürülmektedir[48].

İslam Teolojisinde Uyku Metaforu

Ölüm ve Dirilişin Metaforu Olarak Uyku

İslam teolojisinde uyku, canlılar için biyolojik bir ihtiyaç olmanın ötesinde ölümün küçük bir modeli (küçük ölüm / el-mevtü's-suğra) ve muvakkat bir bilinç kaybı olarak tavsif edilir. Kur'an-ı Kerim'de yer alan ayetler, ruhun bedenle birlikteliğinin zaruri olduğunu vurgulamakla birlikte uyku halinin bu bağın geçici olarak zayıflaması hali olarak açıklar[49]. İslam âlimleri bu durumu, ruhun beden kalıbından kısmen sıyrılması ve ahiretteki büyük uyanışın (haşir ve ba's ba'del-mevt) dünyadaki en net somut göstergesi olarak yorumlamışlardır[50]. Ayrıca Nebe suresin 9. Ayetinde uykunun, canlılar bakımından hayata daha sağlıklı başlamak için bir dinlenme faktörü olduğu ifade edilir.[51]

Bundan başka Kur'ân-ı Kerîm'in Kehf suresinde anlatılan Mağara kıssası da uyku metaforunun, insanların ahirette tekrar dirilişinin bir göstergesi ve ispatı olmakla birlikte yaşadığımız fiziki âlemde de ilahi kudretin bunun örneğini gösterebileceğinin bir delili olarak sunulmaktadır[52].

İlahi Kudret, Nimet ve Manevi Gaflet

Bütün bunlarla beraber uyku, aciz bir varlık olan insanın, bu acziyetiyle birlikte kudreti sonsuz ve aşkın bir yaratıcıya muhtaç oluşunun ve teslimiyetinin mistik bir sembolü olarak ta telakki edilmektedir. Çünkü insan birçok bakımdan aciz bir yaratıktır.

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[46] "Brain Basics: Understanding Sleep | National Institute of Neurological Disorders and Stroke". *www.ninds.nih.gov*. (15 Şubat 2023 tarihinde kaynağından arşivlendi. Erişim tarihi: 15 Şubat 2023).

[47] Joiner WJ (October 2016). "Unraveling the Evolutionary Determinants of Sleep", *Current Biology*. 26 (20): R1073-R1087.

[48] Keene, Alex C & Duboue, Erik R. (12 Haziran 2018). "The origins and evolution of sleep". *The Journal of Experimental Biology*.

[49] *Diyanet İşleri Başkanlığı*, 2019, *Kur'ân-ı Kerîm ve Açıklamalı Meali*. Diyanet İşleri Başkanlığı Yayınları. Zümer Suresi 39:42 "Allah, (ölen) insanların ruhlarını öldüklerinde, ölmeyenlerinkini de uykularında alır. Ölümüne hükmettiklerinin ruhlarını tutar, diğerlerini belli bir süreye (ömürlerinin sonuna) kadar bırakır. Şüphesiz bunda düşünen bir toplum için elbette ibretler vardır". Rum Suresi 23 "Gece olsun gündüz olsun, uyumanız ve Allah'ın lütfundan (nasibinizi) aramanız da O'nun (varlığının) delillerindendir. Gerçekten bunda, işiten bir kavim için ibretler vardır."

[50] Muti'ah, K. S., Rokhani, S., & Murdianto, M. (2025). The nature of sleep in the Qur'an. *Fitua: Jurnal Studi Islam*, 6(2), 229-240. ResearchGate Dergi Bağlantısı

[51] *Diyanet İşleri Başkanlığı,* 2019, *Kur'ân-ı Kerîm ve Açıklamalı Meali*. Diyanet İşleri Başkanlığı Yayınları: "Uykunuzu bir dinlenme (vesilesi) kıldık. Geceyi (uyku için) örtü yaptık. Gündüzü de çalışıp kazanm…" Nebe Suresi 6-11

[52] *Diyanet İşleri Başkanlığı,* 2019, *Kur'ân-ı Kerîm ve Açıklamalı Meali*. Diyanet İşleri Başkanlığı Yayınları: "Bunun üzerine biz de onları sığındıkları o mağarada yıllarca sürecek derin bir uykuya daldırdık."Kehf 18 "Onlar uykuda oldukları halde sen onları uyanık sanırdın. Tek yanlarına yatıp zarar görmemeleri için biz onları kâh sağa kâh sola çeviriyorduk. Köpekleri de mağaranın girişinde ön ayaklarını uzatmış yatmaktaydı. Eğer onları bu halleriyle görseydin dönüp kaçardın ve onlar yüzünden için korkuyla dolardı."

Gündüzleri çalışarak yorulur, dinlenmek için uykuya ihtiyaç duyar. Aynı şekilde çalışırken acıkır ve enerjisini tekrar elde etmek için beslenmek zorundadır. Bu durum tüm canlılarda vaki olan bir ihtiyaçtır. Dolayısıyla çeşitli ayet ve hadislerde beyan edildiği gibi ilahi kudret karşısında aciz ve muhtaç olan canlının, beslenmesi ve uyku nimeti ile dinlendirilmesi yaratıcı tarafından ona ihsan edilmiş bir nimet olarak telakki edilir.

İslam peygamberi, Hz. Muhammed'in uykudan uyandığında okuduğu *"Bizi öldürdükten sonra dirilten Allah'a hamdolsun, dönüş O'nadır"* şeklindeki meşhur duası, canlıların sabahleyin uyanmasının, ahirette yeniden dirilişin bir nevi provası ve hayata daha dinamik bir şekilde başlamanın bir göstergesi olduğunu açıklar[53].

Öte yandan İslam düşüncesinde ve tasavvuf geleneğinde uyku kavramı, insandaki fiziki uyku özelliğinin ve yukarıda bahsedilen fonksiyonlarının dışında mecazen olumsuz anlamları içinde barındıran bir tür olarak ta ele alınmaktadır. Gaflet uykusu, kişinin dünyaya aşırı bağlanarak hakikati ve ahiret bilincini unutması, manevi bir uyku hali ve körlük olarak nitelendirilir. Tasavvufi öğretide, insanın bu yanılgı ve gafletten kurtulup hakikate uyanması sürecindeki ara eşiğe ise yakaza (uyanıklık/farkındalık) adı verilmektedir[54].

Hıristiyan Ve Batı Teolojisinde Uyku Metaforu

Ruhsal Gevşeklik ve Günah: Yeni Ahit'te yani İncil'de uyku kavramı, nispeten İslam tasavvufundaki Gaflet uykusuna benzemektedir. Uykunun bu hali, çoğunlukla dini emirlerde hassas ve uyanık olmama, günah işleme ve hataya düşme konusunda zafiyet halini sembolize eder. Hz. İsa Gethsemane bahçesinde dua ederken havarilerinin uyuyakalması, insanoğlunun zayıflığının ve manevi körlüğünün metaforudur (*Kitabı Mukaddes*[55]).

Mesih'te Uykuya Dalmak: Hıristiyan inancında, inanan birinin fiziksel ölümü için uyku metaforu kullanılır. Bu uyku hali, ölümün korkulacak bir son olmadığını, Hz. İsa'nın ikinci gelişinde (Parousia) gerçekleşecek büyük uyanışa kadar süren geçici bir dinlenme dönemi olduğunu simgeler[56].

Tablo 1. Karşılaştırma Tablosu

Kavram/Boyut	**İslam Teolojisi**	**Hıristiyan/Batı Teolojisi**
Ölüm Metaforu	Ruhun geçici olarak çekilmesi *(küçük ölüm)*	Kıyamet gününe kadar geçici istirahat (*Uykuda Olmak*)
Negatif Anlamı	Hakikatten uzaklaşmak (*Gaflet Uykusu*)	Günaha ve ayartılmaya açık olmak (*Manevi Gevşeklik*)
Uyanış Temsili	Ahiretteki yeniden diriliş (*Haşir*)	İsa'nın dönüşüyle gerçekleşecek diriliş (*Kıyamet*)

Felsefe tarihinde **Platon** ve **Descartes**, uyku metaforunu, insanın algı yanılmaları ve hakikat arayışını açıklamak için kullanmışlardır.

1. Platon: Mağara İstiaresi ve Cehalet Uykusu: Platon'a göre insanlar ideal dünyanın yani rasyonel gerçekliğin farkında değillerdir ve hakikatten uzak derin bir uyku içerisindedirler. Duyular yoluyla algıladığımız bu dünya, uykuda gördüğümüz rüyalardan ibarettir. Filozof ise ruhi ve fiziki yetenekleri sayesinde bu uykudan uyanmış olan ve bilginin hakikatine (episteme) ulaşmış olan kişidir[57].

[53] Buhari, M. b. İ. (s.a.). *el-Camiu's-sahih*. (M. Fuad Abdülbaki, Dü.). Çağrı Yayınları. (Orijinal çalışma yayın tarihi bilinmiyor).
[54] Muti'ah, a.g.e. (2025)
[55] *Kitabı Mukaddes Şirketi*, (2001), *Kutsal Kitap (Eski ve Yeni Ahit)*, Kitabı Mukaddes Şirketi Yayınları. Matta 26:40-41
[56] MacDonald, N. (2017). Death as sleep in the New Testament and early Christianity. *Theological Studies*, 78(4), 843-862.
[57] Platon. (2006). *Devlet* (S. Eyüboğlu & M. Â. Cimcoz, Çev.). Türkiye İş Bankası Kültür Yayınları. (Orijinal çalışma yayın tarihi MÖ y.375)

2. Descartes: Rüya Argümanı ve Radikal Şüphe: Descartes ise duyuların insanı aldatabileceğini ileri sürer, bunu ispat edebilmek için **Rüya Argümanı'**nı kullanır. Rüyada iken, sanki uyanıkmışız gibi her şeyi gerçek sandığımızı, hâlbuki uyanıkken bile gerçek olarak uyanık olduğumuzdan asla emin olamayacağımızı ileri sürer. Descartes'in bu metaforu, onun mutlak bilgiye ulaşmak için her şeyden şüphe ettiği Kartezyen felsefesinin esasını oluşturmaktadır[58].

Divan Edebiyatında Uyku

Gaflet Uykusu (Hâb-ı Gaflet): Klasik Türk edebiyatında ve divan şiirinde uyku, sadece biyolojik olarak bir dinlenme hali değil, insanın dünya nimetlerine dalarak gaflete düşmesi, hakikatten uzaklaşarak manevi körlüğe kapılması şeklinde bir metafor olarak kullanılır[59]. Şairler ise muhataplarını ikaz etmek suretiyle bu gaflet uykusundan uyandırmayı kendilerine misyon edinmiş kişilerdir[60].

Seher Vakti: Seher vakti, edebiyatta ve tasavvufta gaflet uykusundan uyanmanın en kutsal ve etkili zamanıd olarak vasıflandırılır. Buna göre bahar bulutları (ebr-i bahar) bahçedeki çiçekleri uyandırmak için her seher vakti onların üzerine çiy suları serper[61]. Ayrıca seher vakti, insanların fecirle birlikte canlılarla beraber uykudan uyanarak tabiatın lahuti bir atmosfer içinde uyanışını seyredip tefekkür ederek yaratanı zikrettikleri muazzam bir vakittir.

Rüya: İster edebi, ister tasavvufi manada olsun sevgili her an aşığın gönlündedir. Sevgili, aşığın gündüz hayalinde, gece düşündedir ve aşık, her an onun ateşiyle yanıp tutuşmaktadır. Sevgilinin yüzünü (visal) gerçek dünyada göremeyen âşık için uyku, rüya yoluyla sevgiliye kavuşma ümididir. Âşık, uykuda vuslat ümidi olmasa uykunun gözüne haram olacağını düşünür ve ona olan hasretini dile getirir[62].

Halk Edebiyatında Uyku

Ninni: Türk halk kültüründe ve edebiyatında doğumla başlayan süreçte uyku, çocuğun büyüyüp gelişmesi, korunması ve tehlikelerden uzak kalması için sığınılan bir limandır. Ninniler bu sığınmanın en önemli manzum araçlarıdır[63]. Ninni, belli bir yaşa gelinceye kadar anne ile çocuk arasında, onun olgunlaşması bakımından en önemli duygusal iletişim vasıtasıdır.

Rüya ve Bade İçme: Halk edebiyatında ozanların rüya görmeleri ve bade içmeleri onların hem duygusal hem sanatsal hem de kültürel olarak yetişmelerinin ve belli mertebelere ulaşmalarının en önemli göstergesidir. Âşıklık geleneğinde rüya, bir gencin rüyasında kutsal kişiler (pirler, üçler, kırklar) elinden "bade" veya "dolu" içerek uyanması ve bu uykunun ardından şairlik yeteneği (mahlas ve ledün ilmi) kazanması sürecidir. Bu durum, âşıklığa geçişin ilahi bir meşruiyet zeminidir[64].

Bilinçaltı ve Rüya: Modern Türk edebiyatında (Servet-i Fünun ve Cumhuriyet dönemi) rüya ve uyku, Ahmet Hamdi Tanpınar gibi yazarların eserlerinde Freudyen psikolojinin etkisiyle bireysel ve toplumsal bilinçdışına giden bir "kral yolu" olarak ele alınır. Zihin, dış dünyaya kapalıyken bile uykuda dış uyarıcıları işlemeye devam eder.[65]

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[58] Descartes, R. (2014). *Metafizik üzerine düşünceler* (A. Yardımlı, Çev.). İdea Yayınevi. (Orijinal çalışma yayın tarihi 1641).

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[60] Akarsu, B. (2010). Türk edebiyatında rüya motifi ve bu bağlamda rüya ile yönlendirilen karakterler. *Journal of Turkish Studies*, 5(2), 141-155.

[61] Altuntaş, H. (2020). Divan şiirinin/şairinin hâb-ı gafletten ikaz vazifesi. *Akademik Dil ve Edebiyat Dergisi*, 4(1), 120-135. DergiPark.; Kılıç, S. (2023). Divan şiirinde vakt-i seher ve şairlerin seher vaktine yüklediği anlamlar. *İslam Araştırmaları Dergisi*, 49, 85-102. ISAM Makale.

[62] Aydemir, Y. (2019). Klasik şiirde uyku üzerine mülahazalar. *Gazi Türkiyat*, 24, 77-94. DergiPark.

[63] Karataş, M. (2026). Yeni Türk edebiyatında rüya anlatıları: Bireysel ve toplumsal bilinç dışına giden yol. *Yeni Türk Edebiyatı Araştırmaları*, 18(1), 45-62. DergiPark.

[64] Yardımcı, M. (2019). Âşık edebiyatında rüya sonrası âşık olma ve bâde içme geleneği. *Anadolu Bilim Kültür ve Eğitim Dergisi*, 3(2), 150-165. ABKED. [, 2, 3, 4, 5, 6, 7]

[65] Karataş, M. (2026). Yeni Türk edebiyatında rüya anlatıları: Bireysel ve toplumsal bilinç dışına giden yol. *Yeni Türk Edebiyatı Araştırmaları*, 18(1), 45-62. DergiPark.

Şeyh Galib Divanında "Uyku" Metaforu İle İlgili Beyitlerin Tespiti Ve İncelenmesi

Şeyh Galib, Klasik Türk edebiyatının 18. Yüzyılda yetişmiş en önemli figürlerinden biridir. Edebiyat araştırmacıları, tarihçiler ve eleştirmenler hatta Türk edebiyatı ile bir şekilde ilgilenenler, Şeyh Gâlib'i Klasik Türk edebiyatının son ve en güçlü temsilcilerinden biri sayarlar. Şeyh Galib'in, Divan şiirinde ve Tasavvufi Türk edebiyatında yeni yöntem ve buluşlarının yanı sıra dilinin ağır olmasına rağmen mahallileşmeye ve Türk diline genel anlamda katkılarını da göz ardı etmemek gerekir. Şeyh Galib'in sanat anlayışı ve anlatım tarzı da onun ayırt edici niteliklerinden biridir. Nitekim "Şeyh Gâlib gelenekten intikal eden, alışkanlıkların yönettiği bir şiir mekanizması yerine çok defa tesadüfî olmayarak seçtiği vezinleri, kafiyeleri, iç sesleri, girift mazmunları ve itinalı diliyle divan şiirinde son büyük hamleyi yapmış olan bir şairdir. Bu hamlede Sebk-i Hindî akımına mensup şairlerin etkisi önemlidir"[66].

Şeyh Galib, hem tasavvuf geleneğinin hem de Sebk-i Hindî akımının ona kazandırdığı niteliklerle, duygu ve düşüncelerini simgelerle anlatan bir şairdir. "Hüsn ü Aşk" adlı mesnevisi bunun en müşahhas delillerinden biridir. Kaldı ki Divan şiiri, dayandığı anlatım dili ve mazmunlar bakımından, sembollerle ve belli kalıplarla icra edilen bir şiir türüdür. Bu durum, yadırganacak bir hal değildir. Zira insanlar eski çağlardan beri soyut ve girift düşünceleri ve olayları, simgelerden yararlanarak anlatma yolunu seçmişlerdir. Dünya tarihine, edebiyatına ve mitolojisine baktığımızda bu durumu açıkça görmekteyiz. Coomaraswamy'ye göre, "gerçek bir sanat, sembolik ve manalı bir temsilin gerçekleştirilebildiği, yani aklın dışında görülmesi mümkün olmayan şeylerin temsil edildiği sanattır"[67].

Bu bildiri çalışmasında, Prof. Dr. Naci OKÇU'nun hazırladığı ve T. C. Kültür Ve Turizm Bakanlığı Kütüphaneler Ve Yayımlar Genel Müdürlüğü tarafından basılan[68] Şeyh Gâlib divanı esas alınarak, "Uyku Metaforu" ile ilgili beyitler tespit edilmiş, bu beyitlerdeki "Uyku" kavramı ele alınarak değerlendirmelerde bulunulmuştur. Öncelikle, "uyku" metaforunun literatürdeki yeri araştırılmış, daha sonra metin merkezli olarak Şeyh Gâlib'in divanında, bu metaforla ilgili beyitler tespit edilerek beyitler, anlatım biçimi, mazmunlar, Tasavvufi sembol ve kavramları anlamlandırma ve edebi bakımından incelenmiştir.

Literatür taraması ve metin incelemesi yöntemiyle yapılan çalışma sonucunda, Şeyh Gâlib divanındaki "uyku" metaforu ile ilgili **54** beyit tespit edilmiştir. Bu ifade, genel kategoriyi açıklamak için kullanılmıştır. Çünkü konuyla ilgili tespit edilen bazı manzumeler, edebi tür olarak beyitler şeklinde yazılmamıştır (Terci-i Bend, Terkîb-i Bend, müseddes vb…). Şeyh Gâlib, "uyku" kavramını Türkçe "uyku" kelimesi ile değil, Farsça "hâb" kelimesinin karşılığı olarak yazdığından bu kelime ile ilgili beyitler seçilmiş, beyitlerin Türkçe karşılıkları verilmiştir. Konunun sınırlandırılması ve bildiri konusu göz önünde bulundurularak tespit edilen tüm beyitler açıklanmamış, konuyla ilgili dikkat çekici ve vurgulayıcı bazı beyitler açıklanmıştır.

Şeyh Gâlib divanında tespit edilen 54 beyit, birlikte değerlendirildiğinde, divanda "hâb" kelimesinin ve türevlerinin yalnızca gerçek anlamıyla "uyku" için kullanılmadığı görülmüştür. Beyitlerde gerçek anlamının dışında; edebi, tasavvufi, teolojik ve mitolojik olmak üzere değişik anlam katmanlarında kullanılan beyitlerde "hâb", çoğunlukla mecazî ve sembolik bir değer kazanmaktadır. Kısaca Şeyh Gâlib'in şiir anlayışında ve divanında uyku "hâb", tek anlamlı bir kavram değildir. Ona göre uyku kavramı, fiziksel uykudan gaflete, gafletten ölüme, ölümden tasavvufî uyanışa ve marifete uzanan çok katmanlı bir anlam alanıdır.

Beyitlerde kullanılan anlam katmanları dört temel eksende toplanmıştır:

1. **Edebî anlam:** Sevgilinin nazı, göz mahmurluğu, hayal, rüya ve dinlenme hâli
2. **Tasavvufî anlam:** Gaflet, mâsivâya bağlılık, hakikatten perdelenme ve ilahî uyanışın karşıtı
3. **Teolojik anlam:** İnsanın faniliği, ölümün küçük kardeşi olan uyku ve ilahî tecelli karşısında dünya idrakinin sönük kalması
4. **Mitolojik ve kültürel anlam:** İskender, Züleyha gibi klasik şahsiyetlere yapılan telmihlerle kader, talih ve beşerî acziyetin sembolü

[66] Kalkışım, M. Muhsin(2010). "Şeyh Galib", TDV İslam Ansiklopedisi, İstanbul, C.39, s.54-57
[67] Livingston, Ray (1998); Geleneksel Edebiyat Teorisi (Çev. Necat Özdemiroğlu), İnsan Yay., İstanbul
[68] T. C. Kültür Ve Turizm Bakanlığı Kütüphaneler Ve Yayımlar Genel Müdürlüğü, 3146 Kültür Eserleri, 429, Isbn 978-975-17-3353-5

Bu tasnif dikkate alındığında, Divan'daki 54 kullanımın yaklaşık yarısında "hâb"ın fizikî uykudan çok gaflet ve metafizik perdelenme; diğer önemli bir bölümünde ise aşkın doğurduğu hayal, mahmurluk ve rüya hâli anlamlarında kullanıldığı söylenebilir. Bu durum, Şeyh Gâlib'in Sebk-i Hindî akımı ve estetiği içinde "uyku" metaforunu çok katmanlı ve dinamik bir sembole dönüştürdüğünü göstermektedir. Bu nedenle Gâlib'in şiirinde "hâb", fiziksel bir uyku olmaktan çok, insanın manevî, psikolojik ve aşk hâllerini ifade eden güçlü bir metafor olarak işlev görmektedir. Bu da Şeyh Gâlib'in "hâb" metaforunu çok katmanlı bir şekilde kullandığını göstermektedir. Bu çok katmanlı kullanım, "hâb" kelimesinin Divan'da 54 kez geçmesine rağmen her beyitte farklı bir çağrışımı kazanmasını sağlamıştır. Söz konusu anlam katmanları çerçevesinde "hâb" kavramı, tematik olarak sınıflandırılmış ve şu başlıklar altında tasnif edilmiştir:

Hâb = Gaflet (tasavvufî kullanım)
Hâb = Rüya/Hayal (estetik ve psikolojik kullanım)
Hâb = Naz ve Mahmurluk (âşık–maşuk ilişkisi - Sevgilinin ilgisizliği, tegafül)
Hâb = Ölüm ve Fenâ (teolojik kullanım)
Hâb = İmkânsızlık ve Mübalağa (kasidelerde övgü unsuru)
Hâb = Hakikate Uyanışın Zıddı (vahdet-i vücûd ekseni)

Hâb = Vuslat ümidiyle görülen manevi rüya

Tablo 2. Şeyh Gâlib'in "hâb" Metaforunu Kullandığı Anlam Katmanları

Kategori	**Beyit Sayısı (yaklaşık)**	**İçerik**
Hâb = Gerçek anlam (uyku)	8	Fizikî uyku, dinlenme
Hâb = Rüya/Düş-Hayal	12	Rüya, hayal, tahayyül
Hâb = Naz ve Mahmurluk	10	Hâb-ı nâz, mahmurluk, göz
Hâb = Gaflet- Manevi Uyku	15	Tasavvufî anlam
Hâb = Ölüm ve Metafizik	6	Ölüm, fanilik
Hâb = Mitolojik ve Tarihi Telmihler	5	İskender, Züleyha vb.

Dikkat çeken beyitler: Metafor bakımından özellikle aşağıdaki beyitler öne çıkmaktadır. Bu beyitler, "**Uyku Metaforu"**nun en yoğun ve sembolik kullanımlarını temsil eden beyitlerdir.
Kaside 12/11
Kaside 71/30
Müseddes 6
Sâkînâme 8
Gazel 9/5
Gazel 37/5
Gazel 66/2
Gazel 115/4
Gazel 142/6
Gazel 155/4
Gazel 173/1
Gazel 224/4
Gazel 225/1
Gazel 245/1
Gazel 284/3

Örnek Beyit Açıklamaları
(Kaside 12/11)
Ayîne-i zamîr-i tecellî- f ürûzunun Benzer yanında hâb-ı ferâmûşa mâhtâb

Günümüz Türkçesi:
"Senin tecelliler saçan gönül aynanın yanında ay ışığı bile unutulmuş bir uyku gibi sönük kalır."

Edebî anlam:Şair burada gönlü ayna, ilahî nuru ise tecelli olarak tasvir eder. Ay ışığı normalde parlaklığın sembolüdür fakat ilahî tecelli karşısında değersizleşmektedir.
"Hâb-ı ferâmûş" (unutulmuş uyku) ifadesi son derece özgün bir Sebk-i Hindî imgesidir. Uyku artık hatırlanmayan, etkisini kaybetmiş bir hâle dönüşmüştür.

Tasavvufî anlam: Kalp, ilahî tecelliye mazhar olduğunda dünya bütünüyle unutulur. Uyku burada;
- gaflet,
- dünyaya bağlılık,
- Hak'tan uzak oluş anlamlarını taşır (tecelli geldikten sonra gaflet ortadan kalkmıştır).

Teolojik anlam: Kuran'da Allah'ın nuru bütün maddî ışıklardan üstündür[69]. Ay ışığının sönükleşmesi bu anlayışı çağrıştırır.

Mitolojik anlam: Ay (mâhtâb), klasik İran şiirinde güzelliğin sembolüdür. Şeyh Gâlib bu sembolü tersine çevirerek ilahî nur karşısında ayın bile değersiz kaldığını anlatmaya çalışır.

Sonuç: Bu beyitte hâb = gaflet anlamında kullanılmıştır.

(Gazel 245/1)[70]
Hâb ü hayâl-i gafleti âlem sanır gören Mir'ât içinde sûret-i âdem sanır gören

Günümüz Türkçesi:"Görenler gaflet uykusu ve hayalini gerçek dünya sanıyor; aynadaki görüntüyü de gerçek insan zannediyor."

Edebî anlam:Dünya, bir aynadaki görüntü gibidir, gerçek değildir. İnsanlar ise onu hakikat sanırlar.

Tasavvufî anlam: Tam anlamıyla vahdet-i vücûd öğretisini yansıtır.[71] Hakikat yalnız Allah'tır. Dünya; hayal, uyku, gölge, yansıma mesabesindedir[72].

Teolojik anlam:Dünya hayatının geçici gölge oluşu ve aldatıcılığı vurgulanmaktadır.

Mitolojik anlam: Ayna sembolü, İran ve Hint şiirinde hakikatin tecelli ettiği yüzeydir.

Sonuç:
Bu beyitte hâb = dünya cazibesi, gaflet ve hayal şeklinde kullanılmıştır.

(Gazel 155/4)
Sabâh-ı feyzdir rûşendir sürme-i gaflet Demiş yokdur cilâ-yı nûr-ı çeşme hâb olur mâni

Günümüz Türkçesi: Bu, feyzin sabahıdır ve aydınlıktır. Gaflet sürmesi [gözden] silinmiştir. [Çünkü] gözün nurunu parlatacak bir şey yoktur; uyku ona engeldir".
Bu beyitte **sabah, ilahî uyanışı** temsil eder. **Gece** ise gaflettir. Uyku, gözün nurunu örten perde olarak düşünülmektedir (bu durum tezat sanatı ile ifade edilmiştir). Burada özellikle feyiz, sabah, sürme, gaflet, cilâ, nur, çeşme ve hâb kelimeleri birbirine bağlanan bir sembol ağı oluşturmaktadır.

Tasavvufî anlam: Tasavvuf açısından "görmek", fiziksel görmekten çok basiret sahibi olmak, yani hakikati idrak etmektir.
göz–sürme–cilâ–nur–uyku–sabah zinciri, tasavvufî bir dönüşüm meydana getirmiştir. Uyanmak = marifet/ uyku = gaflet olarak vasıflandırılmaktadır.

[69] Nur suresi/35
[70] Bu beyit, Şeyh Gâlib'in "uyku metaforu"nun merkezî örneklerinden biridir.
[71] Eflatun'un "Mağara İstiaresi" de aynı anlamı hatırlatmaktadır.
[72] هُوَ الْاَوَّلُ وَالْاٰخِرُ وَالظَّاهِرُ وَالْبَاطِنُۚ وَهُوَ بِكُلِّ شَيْءٍ عَلِيْمٌ *O (Allah), evveldir, ahirdir, zahirdir, batındır. O, her şeyi (hakkıyla) bilendir.* Hadid suresi/3

Edebî anlam: Beytin merkezinde çok güçlü bir görme metaforu bulunmaktadır. Şeyh Galib, manevî uyanışı doğrudan "uyanmak" diye anlatmak yerine, gözün açılması ve görmeye başlaması üzerinden anlatıyor.
"Sabâh-ı feyz" - "Sabah" burada yalnızca günün başlangıcı değildir. Klasik şiirde gece çoğu zaman karanlık, ayrılık, gaflet ve bilinmezlik ile sabah ise vuslat, keşif, tecelli ve hakikatin ortaya çıkması ile ilişkilendirilir.

Teolojik anlam: Teolojik düzlemde beyit, Allah'ın nuru ile insanın onu algılaması arasındaki ilişkiyi düşündürmektedir.[73]
Burada önemli olan "feyz" kavramıdır. İslâm'da feyz, ilâhî kaynaktan gelen lütuf ve tecellinin varlıklara ulaşmasını ifade etmek için kullanılır. Dolayısıyla Sabâh-ı feyz, sadece "aydınlık sabah" değil, İlâhî lütfun tecelli ettiği zaman anlamına gelebilir. Bu nedenle beyit örtük olarak şöyle bir teolojik önerme taşır: İlâhî hakikat mevcut olduğu hâlde insan, gaflet sebebiyle onu idrak edemez.

Mitolojik Anlam: Buradaki mitolojik katman, doğrudan bir "mitolojik hikâye" anlatımı şeklinde değil; klasik Doğu kozmolojisinin sembolleri üzerinden işlemektedir. Özellikle gece–sabah–ışık–uyku–uyanış dizisi, çok eski bir sembolik yapıya sahiptir. Kadim anlatılarda ve dinî geleneklerde: karanlık → kaos / bilinmezlik / ölüm / uyku ve ışık → yaratılış / düzen / bilgi / hayat karşıtlığı sık görülür. Şeyh Galib bu evrensel sembolizmi İslâmî-tasavvufî bir çerçeveye yerleştiriyor. Burada "sabah", âdeta küçük bir kozmogoni gibi çalışıyor: Karanlık sona eriyor → ışık ortaya çıkıyor → göz açılıyor → hakikat görülüyor. Bu yüzden beyit, yalnızca bir insanın sabah uyanmasını değil, karanlıktan nura geçişi anlatmaktadır.

Sonuç: Burada; hâb = geçici dünya hayatı ve gaflet anlamında kullanılmıştır.

Şeyh Gâlib Divanı'nda "uyku" kavramı, yalnızca fizyolojik bir hâli karşılayan bir kelime olarak değil; gaflet, cehalet, ayrılık, ölüm, nefsin hâkimiyeti, hakikatten uzaklık ve buna karşılık marifet ve uyanış gibi farklı anlam alanlarını kuşatan çok katmanlı bir metafor olarak kullanılmıştır. Çalışmada tespit edilen 54 beyit, baskın anlam katmanları dikkate alınarak edebî, tasavvufî, teolojik, mitolojik ve gerçek anlam olmak üzere beş başlık altında incelenmiştir. Bu çalışmadaki önemli amaçlardan biri de Şeyh Gâlib Divanı'nda kavram olarak geçen "uyku"nun farklı anlam düzlemlerinde nasıl anlam kazandığını göstermektir. Divanda tespit edilen 54 beyit, şöylece beş ana başlık altında toplanmıştır:
1- Edebî/Metaforik Anlamda Uyku
2- Tasavvufî Anlamda Uyku
3- Teolojik Anlamda Uyku
4- Mitolojik/Kültürel Anlamda Uyku
5- Gerçek/Fiziksel Anlamda Uyku

Tespit edilen beş başlık, aşağıdaki tabloda anlam kategorileri bakımından daha detaylı olarak açıklanmıştır.

Teblo 3. Şeyh Gâlib'in Divanında "Hâb" Metaforu İlgili Kullandığı Beyitlerin Tasnifi ve Değerlendirilmesi

Anlam kategorisi	**Beyit Sayısı (yaklaşık)**	**Temel anlam**
Gerçek/fiziksel	8	Fizikî, fiili uyku, dinlenme
Edebî/metaforik	24	Rüya, hayal, tahayyül, Hâb-ı nâz, mahmurluk, göz
Tasavvufî	15	Gaflet–uyanış, marifet, seyr ü sülûk
Teolojik	6	Ölüm, haşir, ilahî kudret vb.
Mitolojik	5	Mitolojik şahıslar/unsurlar üzerinden uyku İskender, Züleyha vb.

[73] اَللّٰهُ نُورُ السَّمٰوٰتِ وَالْاَرْضِ(Allah, göklerin ve yerin aydınlığıdır). Nur suresi/35

Şeyh Galib Divanından Seçilmiş Olan
"Uyku" Metaforu İle İlgili Beyitler Ve Türkçe Karşılıkları
Edebi Tür- Sayı- Beyit
Kaside 12/11
Ayîne-i zamîr-i tecelli-fürûzunun
Benzer yanında hâb-ı feramûşa mâhtâb

Anlamı:*Senin gönlünün, ilahî tecellileri yansıtan aynasının yanında ay ışığı, unutulmuş bir rüya (uyku) gibi sönük kalır.

Kaside 15/28
Cihânda hâb u râhat kalmamışdı belki rü'yâda
Görenler zıll-ı memdûdunda gördü baht-ı didârı

Anlamı:*Dünyada artık uyku ve huzur kalmamış gibiydi; insanlar ancak senin uzun gölgende seni görme mutluluğunu rüyalarında bulabildiler.

Kaside 21/8
Rü'yâda görmez idi bu feyz-i küşâyişi
Ebr-i bahârın olsa şeker hâbı sebîl

Anlamı:*Bahar bulutu şeker gibi tatlı bir uykuya dalsaydı bile, bu kadar büyük bir bereket ve açılışı rüyasında göremezdi.

Kaside 25/16
Reng-i rûhu gözümde uçar ol perî-veşin
Kim tâb'-ı rûzeden yıkılıp mest-i hâb olur
Anlamı:
*Gündüzün yorgunluğuyla uykuya dalan o peri gibi güzelin yanağının rengi gözümün önünden hiç gitmiyor.

Kaside 71/30
Kurduğu asker-i tertîb-i umûr-ı mülkü
Görmedi hâbda İskender-i Yunânî zâd

Anlamı:*Ülkenin işlerini düzenlemek için organize ettiği orduyu, Yunan asıllı İskender bile uykusunda (rüyasında) görmemiştir.

Terci-i Bend 11/
Aşk bir şem'-i ilâhîdir benim pervânesi
Şevk bir zencîrdir gönlüm anın dîvânesi

Eylemiş zülfün perîşân rûy-i âteş-tâbda
Hâb-ı mahmûrâne-i çeşmin gören mehtâbda

Ol siyeh mest-i nigeh mey nûş eder mihrâbda
Ben hayâl-i kâkül ile böyle pîç ü tâbda
Söylenir bu güft ü gûlar meclis-i ahbâbda
Aşk" ol efsâne zann eyler hayâl-i hâbda

Anlamı:Aşk, ilahi bir mumdur, ben ise onun pervanesiyim. Şevk ise gönlümün, onun divanesi olduğu bir zincirdir.Dağınık saçların, ateş gibi yanan parlak yüzüne dökülmüş; ay bile senin mahmur bakışlarının uykulu hâlini görünce etkilenmiştir. Ben ise saçlarının hayaliyle kıvranıp durmaktayım. Dost meclislerinde bunlar konuşulur; aşk ise bunların hepsini, bir uyku hayalinde efsane sanır.

Terkîb-i Bend 12/
Oldu hazân mâ-hasal-ı nev-bâhârımız
Pîrâne geçdi hayf bizim rûzgârımız

Ol hânmân-ı şebnem olan gül olup harâb
Esdi nesîm-i hoş yerine âh-ı şu'le-tâb
Gülşende îş ü nûşa bedel şimdi sûz ü tâb
Sahbâ-yı eşk-i bülbüle gül-goncalar kebâb
Sevdâ-yı aşk u zülf-i perîşân-ı hayâl-i hâb
Yokdur süâl olunsa beğim bundan ey cevâb

Anlamı: Bana, hayatımın neyden ibaret olduğu sorulsa; aşkın sevdası ve uyku hayalindeki dağınık saçlardan başka vereceğim daha güzel bir cevap yoktur beyim! (Son beytin Türkçe karşılığı verilmiştir).

Müseddes 6/
Vaslın hayat-bahş-ı bedendir dedim dedi
Bunlar hayâl ü hâb-ı girânın durur senin

Tutdum o sanat ile ki semt-i tecâhülü
Çeşmi unutdu şîve-i **târz-ı tegâfülü**
Göstermedim o meh-veşe rûy-ı tekâsülü
Der-pîş edînce sûret-i hüsn-i te'emmülü

Anlamı: Sana kavuşmak, insana hayat verir." dedim. O ise, "Bunların hepsi senin, hayallerin ve derin uykundan başka bir şey değildir." dedi.

Sâkînâme 8/
Varırsan ey gönül yem-i aşkın verâsına
Benden selâm et ol târafın âşinâsına

Sâkî getir meyi ki sânadır hitâb-ı aşk
Her yüzden oldu gerçi suâl ü cevâb-ı aşk
Açıldı âftâb zuhûr etdi hâb-ı aşk
Zülfün verilmiş ârızına pîç tâb-ı aşk

Anlamı:
Ey gönül, aşk denizinin ötesine varırsan (veya gözyaşı denizinin verasına ulaşırsan) o tarafın aşinası olanlara (metafizik aşkın, ilahi aşkın marifetine erenlere) benden selam söyle.
Sakî, aşk şarabını getir, zira aşkın hitabı sanadır. Eğer sen şarabı sunarsan, aşkın her türlü soru ve cevabı her tarafta görülmeye başlar (aşkın şarabına kanarsan, marifetulah adına her yerde ve mekânda onun tecellilerini görme imkânını elde edersin).
Güneş doğdu; aşkın uykusu sona erdi (âşık gafletten uyandı) ve aşk ortaya çıktı (Hak tecelli edince bütün karanlıklar aydınlanır ve tüm sorular cevabını bulur).
Sevgilinin zülüfleri, yanağının üzerine kıvrım kıvrım dökülünce aşkın nedenli etkileyici, cazibedar ve bir o kadar da zorluklarla iç içe olduğu anlaşılır.

Tahmis 14/
Safâ-yı hâtırım var yâr ile bezm-i cân oldum
Cemâl-i yâre göre âyîne-dâr-ı hayretim şimdi

Anlamı: Gönlüm huzur ve neşe içindedir; çünkü sevgiliyle can cana, ruh ruha bir meclis kurdum. Şimdi sevgilinin yüzünün güzelliği karşısında, şaşkınlık ve hayranlık aynası tutmaktayım (güzelliği karşısında büyülenmiş, donakalmış durumdayım).

Hele mest etdim ol sîmin-teni hayli alıp hâmın
Çözüp bend-i kâbâsın gülşen etdim cism-i gül-fâmın
Sarıldım câme-hâb-ı nâz içinde sorma encâmın

Anlamı: Nihayet o gümüş tenli sevgiliyi, ürkekliğini ve nazını ortadan kaldırarak onu, (şarapla veya aşkla) olabildiğince sarhoş ettim.
Nihayet elbisesinin bağlarını çözüp, o gül renkli bedenini bir gül bahçesine çevirdim. Naz dolu **uyku** yatağında ona öyle bir sarıldım ki; sonunun nasıl olduğunu sorma!

Tahmis 14/
Beyâz-" gerdeninde hâl-i anber-bûyunu öpdüm
Dil-i agyâre el-hak dâg-ı sûz-ı hasretim şimdi
Uyandım hâb-ı gamdan müjde-i şîrîn-i vuslatla
Dimâgın çeşn-i yâb oldu şehd-i ayn-ı ibretle
Leb-i tâbiri tağyîr oldu ağyârın bu gayretle

Anlamı: Sevgilinin beyaz boynundaki güzel, mis kokulu (amber kokulu) beni öptüm. Fakat şimdi yabancıların, rakiplerin (ağyârın) yüreğinde oluşan hasretlik (kıskançlık) ateşinin korunu görmeye doğrusu hasretim.

*Tatlı kavuşma müjdesiyle gam uykusundan, yani kederli ve karanlık uykudan (rüyadan) uyandım.
*Bu uyanış ve ibret pınarının tatlı suyu ile zihnin, aklın (dimağın) tat aldı, hakikati fark ettin.
*Bu çaba ile rakiplerin bu çaba ve gayretle durumu açıklayan dudakları, sözlerinin ve tabirlerinin rengi değişti, rakipler şaşkınlık ve çaresizlik yaşadı.

Tahmis 15/
Gayrı dil Mısrına şâh olma degildir kâr"
Badezîn ister ise şâhid-i pâzâr olsun
Cûy-ı eşkimle olup bâI-ı cemâli sîrâb
Nergis-i şûhınu çok eyledi ser-mest-i itâb
Sunsun artık nigeh-i çeşmine peymâne-i hâb

Anlamı: Artık gönül Mısır'ına sultan olmak benim için bir kâr, kazanç veya amaç değildir. Mısır", güzellik, zenginlik ve Hz. Yusuf'un sultan olduğu ülke olarak geçer. Şair, "Artık gönlümü dünya güzelliklerinin sultanı yapmakla ilgilenmiyorum, bu makamları gözüm görmüyor".
Bundan sonra o sevgili, isterse sokak pazarlarında (vitrinlerinde) herkesin gördüğü bir güzel olsun.
Sevgilinin güzellik bahçesi, benim gözyaşımın akarsuyuyla, suya kandı, yeşerdi. "Âşığın döktüğü gözyaşları, sevgilinin güzelliğini besleyen, onu daha da canlandıran bir pınar gibidir".
Bu durum, onun o şuh ve cilveli nergis gözünü, sitem ve azarlama sarhoşu yaptı. "Divan edebiyatında sevgilinin gözü nergise benzetilir. Âşığın ağlaması ve ısrarı, sevgilinin gözlerinde bir sitem, kızgınlık ve naz sarhoşluğu yaratmıştır. Sevgili, âşığa sitemle bakmaktadır".
Artık onun o sitemkâr gözünün bakışına uyku kadehi (peymâne-i hâb) sunulsun; o gözler artık uyusun ve dinlensin. "Şair, yaşanan tüm bu fırtınaların, sitemlerin ve ağlamaların ardından bir durulma arar. Sevgilinin o can yakan, sitem eden bakışlarının artık uykuya dalarak sakinleşmesini, araya bir huzur ve sükûnet girmesini arzular".

Muhammes 2/
O mehin meclîsi reşk-âver-i hurşîd olsun
Sâyesi hâb-geh-i çeşm-i sitem-dîd olsun
Gâhîce bâri gönül nâil-i ümmîd olsun
Varalım bezmine vuslat yine tecdîd olsun
Gecemiz Kadr-i mübarek günümüz'îd olsun

Anlamı: O ay yüzlü sevgilinin meclisi, güneşi bile kıskandıran bir yer olsun.
Onun gölgesi, aşkından çok acı çekmiş ve zulüm görmüş gözlerin dinlenip uyuyacağı, uyku yatağı/(sığınağı) olsun.
Hiç değilse ara sıra şu yaralı gönül, umut ettiğine kavuşsun da muradına ersin.
O sevgilinin meclisine, eğlence ortamına varalım da kavuşma sevincimiz yeniden tazelensin.
Gecemiz mübarek Kadir Gecesi gibi kıymetli, gündüzümüz ise bayram günü gibi coşkulu olsun.

Mesnevi 1/
Aceb sakf mı bâl-ı ânkâ mıdır
Per-i bâliş-i kâkül-i hâb-ı nâz
Keç endâmı dîvâr-ı mehtâb-ı nâz
Per-i bâlişi kâkül-i hâb-ı nâz
Bu hem târh-ı beyt-i Zelîhâ değil
Anın gördügü hâb-ı hulyâ değil

Anlamı: Bu, acaba göğün tavanı mı yoksa Anka kuşunun kanadı mı? Naz uykusundaki sevgilinin saçları, yastığı tüy gibi hafif göstermektedir.
Nazla duran sevgilinin ince bedeni ay ışığına benzeyen bir duvar gibidir; naz uykusundaki saçları ise yastığının tüyü gibidir.
Bu, Züleyha'nın hikâyesi değildir; onun gördüğü de sıradan bir hayal veya düş değildir.

Hikâye-i Bâyezid 10/
Şeker hâb etdi bâI etfalını gark
Kedûlar kelle-i kand oldu lâ-fark

Anlamı: Tatlı bir kış uykusu, bahçenin taze çocuklarını [fidan ve goncalarını] bütünüyle içine aldı / boğdu.

Hikâye-i Bâyezid 10/
Müheyyâ herkese her gûne maksûd
Cihân pür-hâb ü ber bîdar-ı nâbûd

Anlamı: Herkes maksadına kavuşmuş gibiydi; bütün dünya baştanbaşa **uykuya dalmış,** uyanık kimse kalmamıştır. Uyanık olan tek şey ise yokluğun kendisidir.

Gazel 9/5
Beste-i hâb-I şeb-i hayret iken sagar-ı mey
Meş'al-i kâfile-i râh-ı Hudâ geldi bana

Anlamı: Hayret gecesinin uykusuna dalmışken, şarap kadehi bana Allah yolunun kafilesine yol gösteren bir meşale gibi ulaştı.

Gazel 12/1
Ey çeşm-i mesti kûşe mihrâb-âşinâ
Gamzen ne hastadir ki olur hâb-âşinâ

Anlamı:Ey mahmur gözlü sevgili! Yan bakışın nasıl bir derde tutulmuştur ki sürekli uykuya meyleder.

Gazel 16/7
Safâdan uçsa da deryâ-yı meyden olmaz dûr
Bat-ı şarâb gibi murg-ı hâb-ı âlem-i âb

Anlamı: Uyku âleminin kuşu**,** denizde yaşayan ördek gibi, ne kadar uçsa da huzur ve neşe denizinden uzaklaşmaz.

Gazel 18/7
Seng-i nişân-ı hâbda tîz eyler el-hazer
Tîg-i nigâh" sanma girân hâbdır bu şeb

Anlamı: Bu gece onun bakışını uyuyan bir kılıç sanma; dikkat et, uyku bile tehlike taşır.

Gazel 29/2
Çeksin el pençe-i müjgânına vermez zahmet
Kâkül-i hâb-ı perîşânımıza şâne abes

Anlamı: Tarak boşuna uğraşmasın; uykudan dağılmış saçlarımızı taramaya gücü yetmez.

Gazel 37/5
Bâlîn-i şeker-hâb-ı ferâğatdır o Gâlib
Berg-i gül-i hasretden ise mâye-i dûzah

Anlamı: Ey Gâlib! Kaygısızlığın tatlı uykusu yumuşak bir yastık gibidir; hasretin gül yaprağı ise cehennem ateşinin kaynağıdır.

Gazel 43/4
Hayâl-i hattın eder hâbı tûtîyâ gözüme
Degildir âşık-ı şeb zinde-dâra hâb-lezîz

Anlamı: Sevgilinin ayva tüylerinin hayali gözlerime uyku gibi gelir; fakat geceleri uyanık kalan âşık için uyku artık tatlı değildir.

Gazel 50/2
Döner sahîfe-i Erjenge bâliş-i hıştım
Gehî ki cilve-i nâzı hayâl-i hâba gelir

Anlamı: Nazlı sevgilinin cilvesi **rüyama** girince, taş yastığım bile nakışlı bir resim sayfasına dönüşür.

Gazel 66/2
Hâbîde nigehler ne bilir cezbe-i hüsnü
A'mâ gibi mir'âta bakup târ görürler

Anlamı: Uykuya dalmış bakışlar güzelliğin çekiciliğini anlayamaz; körlerin aynaya bakıp karanlık görmesi gibidir.

Gazel 67/6
Gözden uçurdu hâbımızı hatt-ı püşt- leb
Gûyâ tezerv-i nağme-i rengîne bâldır

Anlamı: Dudağının üzerindeki ince tüyler uykumuzu kaçırdı; sanki renkli ezgiler söyleyen bir sülün kanadı gibiydi.
(Bu bölümde de "hâb"ın çoğunlukla gerçek uyku, mahmurluk, rüya ve gaflet anlam katmanlarıyla kullanıldığı görülüyor).

Gazel 81/6
Düşünde tâli-i hâbîde kim göre yarın
Olursa bâl-i hümâ ana bâd-zen yaraşır

Anlamı: Yarını uykusunda talihli bir rüya olarak gören kimsenin başına, devlet kuşunun kanat çırpması yakışır.

Gazel 98/2
Eder rûşen ümmid-i hâb-ı vuslat dîde-i bahtım
Çeh-i sîmîn zenehdân-ı hat-âver sürmedânımdır

Anlamı: Kavuşma rüyası ümidi talihimin gözünü aydınlatır; sevgilinin gümüş gibi çenesi benim sürme kutum gibidir.

Gazel 108/2
Olamaz ol sebz-i teh gülgûn-ı meste hâb-gâh
Olsa bir feyz ile Câmînin Bahâristânı sebz

Anlamı:Câmî'nin *Baharistan*'ı bile yeniden canlansa, o yeşillikle dolu çemenistanı, sarhoş sevgiliye uyuyacağı bir yer olamaz.

Gazel 115/4
Hâb-ı girâna rıtl-ı girân eyledik bedel
Yokdur tarîk-i gamda bizim seng-i râhımız

Anlamı: Derin uykuyu ağır bir şarap kadehiyle değiştirdik; keder yolunda bizi durduracak hiçbir engel yoktur.

Gazel 116/4
Gamzesin **hançer-i hâbîde** sanırsın ammâ
Uyudur fitneyi havf-ile o fettân uyumaz

Anlamı: Onun yan bakışını **uyuyan bir hançer** sanırsın; oysa fitneyi korkudan uyutur, kendisi ise hiç uyumaz.

Gazel 138/5
Hemân ta'bîri pîç ü tâbdır Gâlib dil-i zâra
Tırâş edip hat-ı rüyûn **hayâl-i hâb** göstermiş

Ey Gâlib! Zavallı gönlün bütün yorumu karmaşa ve kıvranıştır; sevgili yüzündeki tüyleri keserek insana bir rüya hayali göstermiştir.

Gazel 142/6
Der-hâb olanın üstüne togmaz mı aceb mâh
Devlet melegim tâli-i bîdâra mi mahsûs

Anlamı: Ay, uyuyanların üzerine de doğmaz mı? Ey talih meleğim, mutluluk yalnız uyanık olanlara mı aittir?

Gazel 155/4
Sabâh-ı feyzdir rûşendir sürme-i gaflet
Demiş yokdur cilâ-yı nûr-ı çeşme hâb olur mâni

Anlamı: Feyiz sabahı gelmiştir; gaflet sürmesi silinmiştir. Gözün nurunu parlatmaya engel olan şey uykudur**.**

Gazel 161/5
Urdu baht-ı siyehim târ-ı harîr-i şebden
O mehe perde-keş-i hâb-ı tegâfüldür zülf

Anlamı: Kara talihim gecenin ipek ipliğine bağlandı; sevgilinin saçları ise onun ilgisizliğinin uyku perdesidir.

Gazel 166/1
Ey nev -bahâr-ı hüsnü şafak-tâb-ı gül arak
Hatt-ı lebi hayâl-i şeker-hâb-ı gül arak

Anlamı: Ey güzelliği ilkbahar gibi taze olan sevgili! Dudaklarının ince tüyleri, gül kokulu tatlı bir uykunun hayalini andırır.

Gazel 173/1
Basılma neş'eye tâ **mes**t-i hâb oluncaya dek
Yapılma kaydına düşme harâb oluncaya dek

Anlamı: Uyku sersemliğine düşecek kadar neşeye kapılma; tamamen perişan oluncaya kadar da hiçbir şeye bağlanma.

Gazel 192/2
Hünâbe-hîz-i girye reg-i hâbdır banBîdâr-ı âb-ı hançer-i berrân kim senin

Anlamı: Kanlı gözyaşı dökmek bana uykusuzluk damarı gibidir; senin parlak hançerin ise daima uyanıktır.

Gazel 203/3
Şeb-i vefâda mülâkâtı ile yârânın
Safâ-yı rıtl-ı girân var gözümde hâb degil

Anlamı: Vefa gecesinde dostlarla buluşmanın verdiği sevinçten gözümde **uyku** değil, ağır şarabın neşesi vardır.

Gazel 224/4
Mest ola ser be-bâliş-i hâb ol semen-i zâr
Ben tâ seher bu tâli'-i bîdârı neyleyim

Anlamı:O yasemin gibi güzel başını uyku yastığına koyup uyusun; ben sabaha kadar bu uykusuz talihle ne yapayım?

Gazel 225/1
Aşkım hâb n'idiğin bilmem
Âteşim âb n'idiğin bilmem

Anlamı:Aşkımdan dolayı uykunun ne olduğunu bilmem; ateş olduğumdan, suyun ne olduğunu da bilmem.

Gazel 234/5
Ol semender-meniş ey tâ'ir-i hâb-ı râhat
Verme hâkisterini pister-i sincâba sakın

Anlamı: Ey rahatlık uykusunun kuşu, ateşte yaşayan semender gibi ol; küllerini sakın samur döşeğine bırakma.

Gazel 234/6
Şeb-i tenhâda peri-zâd-ı hayâl olmaz dûr
Bakma ey meh yalnız **âyîne-i hâb**a sakın

Anlamı: Yalnızlık gecesinde hayallerden doğan periler uzak değildir; ey ay yüzlü sevgili, yalnız başına uyku aynasına dalıp gitme.

Gazel 245/1
Hâb ü hayâl-i gafleti âlem sanır gören
Mir'ât içinde sûret-i âdem sanır gören

Anlamı: Bakan kişi gafletin uyku ve hayallerini gerçek dünya sanır; aynadaki görüntüyü de gerçek insan zanneder.

Gazel 256/6
Nûş-ı lebin hayâl ile Şîrîn-hâb idim
Zenbûr-ı fikr-i firkati dört yanm almadan

Anlamı: Dudaklarının hayaliyle tatlı bir rüyaya dalmıştım; ayrılık düşüncesinin arıları dört bir yanımı sarmadan önce.

Gazel 265/4
Surh-rûy-i haclet eyler hançer-i hâbîdeni
Olma gâfil hûn-ı çeşm-i âşık-ı dil-rîşden

Anlamı: Uyuyan hançerin bile utançtan kızarır; gönlü yaralı âşığın gözyaşından habersiz olma.

Gazel 271/4
Neş'e-i nâz degil **serhôşî-i hâb** degil
Nergis-i şûhundaki bûy-ı tegâfüldür

Anlamı: Bu ne nazın neşesidir ne de **uykunun serhoşluğu**; o, sevgilinin nergis gibi gözlerindeki ilgisizlik havasıdır.

Gazel 284/3
Mâhtâb eyledim âyîne-i baht-ı siyehi
Tîg-i hâbide**-i gamze**n-veş uyandım bu gece

Anlamı: Kara talihimin aynasını ay ışığıyla aydınlattım; bu gece sevgilinin uyuyan kılıç gibi keskin bakışı misali uyandım.

Gazel 289/2
Çeşm-i hâb-âlûde-i baht-ı siyâhımdır benim
Bak riyâz-ı hayretin berk-i gül ü şebbûsına

Anlamı: Benim kara talihimin gözü hâlâ **uykuludur;** hayret bahçesindeki gül ve şebboy yapraklarına bir bak!

Gazel 324/1
Senin ey cân şehîd-i çeşm-i hûn-hâr oldugun var mı
Kanup hâb-ı humâra mest-i bîdâr oldugun var mı

Anlamı: Ey sevgili! Hiç kan dökücü gözlerinin kurbanı oldun mu? Hiç mahmurluk uykusuna kanıp uyanık bir sarhoş oldun mu?

Gazel 328/6
El-hazer gâfil bulunma hançer-i hâbîdeden
Güft ü gûy-i katldır dâim anın efsânesi

Anlamı: Dikkat et, uyuyan hançere aldanma; onun bütün hikâyesi öldürmek üzerinedir.

SONUÇ

Şeyh Gâlib'in Divanı'nda "uyku" metaforunun incelendiği bu çalışmada, "hâb" ve türevlerinin yalnızca biyolojik bir ihtiyaç olan uyuma hâlini ifade etmediği, aksine şairin şiir dünyasında çok katmanlı ve sembolik bir anlam alanına sahip olduğu görülmüştür. Çalışma kapsamında tespit edilen 54 beyit, edebî, tasavvufî, teolojik, mitolojik ve gerçek anlam düzlemlerinde değerlendirilmiş; bu kullanımların Şeyh Gâlib'in kendine özgü şiir anlayışının ve Sebk-i Hindî estetiğinin önemli unsurlarından biri olduğu sonucuna ulaşılmıştır. İncelenen beyitler, "hâb" kavramının özellikle gaflet, mâsivâya bağlılık, hakikatten perdelenme ve manevî uyanışın karşıtı olarak tasavvufî bir anlam kazandığını göstermektedir. Bu bağlamda uyku, insanın hakikati idrak etmesini engelleyen bir perde; uyanmak ise marifete, tecelliye ve hakikate ulaşmanın sembolü hâline gelmektedir. Şeyh Gâlib'in şiirlerinde gece–uyku–gaflet ile sabah–uyanış–feyiz–nur arasında kurulan karşıtlık, bu anlayışın en belirgin göstergelerindendir. Özellikle "sabâh-ı feyz" etrafında kurulan anlam dünyasında sabah, yalnızca fiziksel bir zaman dilimi olmaktan çıkarak ilahî lütfun ve manevî idrakin ortaya çıkışını temsil etmektedir. Böylece uyku = gaflet, uyanış = marifet biçiminde özetlenebilecek sembolik bir tezat ortaya çıkmaktadır. Bunun yanında "hâb", Şeyh Gâlib'in divanında yalnızca tasavvufî bir kavram olarak değil; rüya, hayal, naz, mahmurluk, sevgilinin ilgisizliği, vuslat ümidi, ölüm ve fenâ gibi farklı anlam alanlarını da karşılamaktadır. Özellikle âşık-mâşuk ilişkisi içerisinde uyku ve rüya, gerçek dünyada gerçekleşmeyen vuslatın hayal düzlemindeki imkânı olarak karşımıza çıkmaktadır. Buna karşılık aşkın şiddetinin anlatıldığı bazı beyitlerde uyku, insanın doğal ve fiziksel ihtiyaçlarından biri olarak ele alınmakta; ancak bu gerçek anlam bile aşkın dönüştürücü gücü içerisinde yeni ve farklı bir anlam kazanmaktadır. "Âşkım hâb n'idiğin bilmem / Âteşim âb n'idiğin bilmem" beytinde olduğu gibi aşk, insanın alışılmış ihtiyaçlarını ve gündelik varoluş biçimini aşan bir hâle dönüşmektedir.

Çalışmanın önemli sonuçlarından biri de Şeyh Gâlib'in "hâb" kavramını farklı sembollerle birlikte kullanarak geniş bir anlam ağı oluşturmasıdır. Ayna, göz, nur, sürme, sabah, gece, ateş, su, ay ve tecelli gibi unsurlar "hâb" kavramının anlamını tamamlayan veya dönüştüren semboller olarak işlev görmektedir. Böylece tek bir kelime, beyitin bağlamına göre farklı çağrışımlar kazanmakta ve okuyucuyu görünenden görünmeyene doğru ilerleyen bir anlam yolculuğuna çıkarmaktadır. Bu durum, Sebk-i Hindî akımının temel özelliklerinden olan yoğun hayal, girift tasvirler, uzak çağrışım ve anlamı ilk bakışta kolayca ele vermeyen söyleyiş biçimiyle de doğrudan örtüşmektedir.

Sonuç olarak Şeyh Gâlib Divanı'nda "hâb", fiziksel uykudan ziyade insanın hakikat karşısındaki konumunu açıklayan dinamik bir metafor niteliğindedir. Uyku bazen gaflet ve perdelenmeyi, bazen dünya hayatının geçiciliğini, bazen rüya ve hayali, bazen sevgilinin nazını ve vuslat beklentisini, bazen de aşkın, insanı dönüştüren gücünü ifade etmektedir. Dolayısıyla 54 beytin bütünü değerlendirildiğinde "hâb"ın tek bir anlama indirgenemeyeceği; aksine Şeyh Gâlib'in şiirinde gafletten marifete, karanlıktan nura, hayalden hakikate ve ayrılıktan vuslata geçişi sağlayan temel sembollerden biri olduğu anlaşılmaktadır. Bu yönüyle "uyku" metaforu, Şeyh Gâlib'in divanında; tasavvufî düşüncesini, Sebk-i Hindî estetiğini ve özgün hayal dünyasını bir arada değerlendirmeye imkân veren önemli bir anahtar kavram olarak karşımıza çıkmaktadır.

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CUMHURİYET DÖNEMİ ESERLERİNDE FİİLİMSİLERİN KULLANIMI ÜZERİNE

ON THE USE OF VERBALS IN WORKS FROM THE REPUBLICAN PERIOD

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ÖZET
Güncel Türkçe Sözlük'te "olumlu veya olumsuz fiillere belirli ekler getirilerek yapılan, geçici isim, sıfat, zarf olarak kullanılan isim-fiil, sıfat-fiil ve zarf-fiilin genel adı; eylemsi" biçiminde tanımlanan fiilimsiler, Türk dilini diğer dillerden ayıran belli başlı dil bilgisi özelliklerinden biridir. Diğer dillerde (İngilizce, Almanca vb.) cümleler birbirine sözcük düzeyindeki cümle bağlayıcılarla bağlanmış ve bu bağlayıcılar Türkiye Türkçesindeki fiilimsilerin görevini üstlenmiştir. Türkçede ise cümle/cümlelerde zaman, miktar, derece kavramı fiilimsi ekleriyle sağlanmaktadır. Fiilimsiler, Türkçede anlatım gücü kazandırırken anlatılanları kısa ve kolay yoldan anlatmayı sağlayan, gereksiz tekrarları önleyen ve söz dizimsel olarak cümleleri birbirine bağlayan unsurlardır. Bu çalışmada Cumhuriyet Dönemi eserlerinde fiilimsi eklerinin kullanımı üzerinde durulmuştur. Çalışmada öncelikle isim-fiiller, sıfat-fiiller ve zarf-fiiller hakkında bilgi verilmiş ardından bunların Cumhuriyet dönemindeki kullanımları ve kullanım sıklıklarına değinilmiştir. Çalışmaya malzeme olarak Orhan Midhat Barbaros'un 1925 yılında yayınlanan *Meçhul Kan* adlı eseri alınmıştır. Buna göre, eserde isim-fiil eklerinden *-mA* ve *-mAk*, sıfat-fiil eklerinden *-AcAk, -An, -DIk/-DUk, -mIş/-mUş* ve zarf-fiil eklerinden ise *-A, -ArAk, -DIkçA/-DUkçA, -IncA/-UncA, -ken, -mAdAn, -Ip/-Up, -r -mAz* eklerinin yaygın olarak kullanıldığı görülmüştür. Bu da Cumhuriyet Dönemi'nde başka bazı fiilimsi ekleri olmasına rağmen sözü edilen fiilimsi eklerinin daha çok tercih edildiğini göstermektedir. Bu durum dönemsel özellikler yanında Cumhuriyet Dönemi eserlerini oluşturan yazar/yazarların kendi tercihleriyle de açıklanabilmektedir. Bu çalışmanın hem Cumhuriyet Dönemi hem de bu dönemde kullanılan fiilimsilere açıklık getirmesi bakımından bu alanda çalışma yapacak araştırmacılara katkı sağlaması düşünülmüştür.
Anahtar Kelimeler: Cumhuriyet Dönemi, fiilimsi, Meçhul Kan, Orhan Mithat Barbaros.

ABSTRACT
Verbals, defined in the Contemporary Turkish Dictionary as "the general term for noun-verbs, adjective-verbs, and adverb-verbs formed by adding specific suffixes to positive or negative verbs and used as temporary nouns, adjectives, or adverbs; verbal forms", are one of the key grammatical features that distinguish the Turkish language from other languages. In other languages (English, German, etc.), sentences are linked together at the word level using sentence connectors, and these connectors serve the same function as verbals in Turkish. In Turkish, however, the concepts of time, quantity, and degree in a sentence or sentences are expressed using verbals. In Turkish, verbals are elements that enhance expressive power, allow for concise and straightforward expression, prevent unnecessary repetition, and connect sentences syntactically. This study focuses on the use of verbals in works from the Republican period. The study first provides information on noun-verbs, adjective-verbs, and adverb-verbs, and then discusses their usage and frequency of use during the Republican period. The source material for this study is Orhan Midhat Barbaros's work Meçhul Kan, published in 1925. Accordingly, the study found that the gerund suffixes -mA and -mAk, the participle suffixes -AcAk, -An, -DIk/-DUk, -mIş/-mUş, and the adverbial participle suffixes -A, -ArAk, -DIkçA/-DUkçA, -IncA/-UncA, -ken, -mAdAn, -Ip/-Up, and -r -mAz are widely used in the work. This shows that, although there were other verbals in the Republican period, the ones mentioned were used more frequently. This situation can be explained not only by period-specific characteristics but also by the personal preferences of the authors who produced the works of the Republican period. It is hoped that this study will contribute to researchers in this field by shedding light on both the Republican period and the verbals used during that period.
Keywords: Republican Oeriod, verbals, Meçhul Kan, Orhan Mithat Barbaros.

GİRİŞ

Filimsi *Güncel Türkçe Sözlük*'te "olumlu veya olumsuz fiillere belirli ekler getirilerek yapılan, geçici isim, sıfat, zarf olarak kullanılan isim-fiil, sıfat-fiil ve zarf-fiilin genel adı; eylemsi" biçiminde tanımlanmaktadır (URL-1).

Kaynaklarda fiilimsiler üzerine ileri sürülen görüşler şöyledir:

Mehmet Hengirmen, "fiilden türeyen, tümleç olabilen, olumsuzu yapılan ancak fiil çekimine girmeyen sözcüklere fiilimsi" demiştir (Hengirmen, 1995, s. 248).

Misalli Büyük Türkçe Sözlük'te fiilimsi "fiilden türetilen, ancak çekime girmeyip yalnız olumsuzu yapılabilen, fiil ismi, isim-fiil ve zarf-fiilin ortak adı" olarak tanımlanmıştır (Ayverdi, 2005, s. 959).

Tahsin Banguoğlu, fiilimsiler için *yatık fiiller* ifadesini kullanmış; fiilin isimleşmiş şekilleri sayılan *yatık fiillerin* fiil, kişi eki almadığını ve ancak tamamlanmamış bir yargıya yüklem olduklarını, bitmemiş fiil adını da buradan aldıklarını belirtmiştir (Banguoğlu, 2011, s. 359, 414).

Muharrem Ergin, fiilimsileri, fiil çekim ekleri içerisinde değerlendirmiş; "partisipler" (isim-fiil) ve "gerundiumlar" (zarf-fiil) başlığı altında vermiştir (Ergin, 2009, s. 333-338).

Süer Eker de Muharrem Ergin gibi fiilimsileri, fiil çekim ekleri içerisinde *eylemsiler* başlığı altında ele almış ve fiilimsileri "söz ya da cümle içinde fiil adı olmaları nedeniyle adı, niteledikleri için sıfat, iki cümleyi bağladığı için bağlaç olabilen ve yüklem görevinde bulunabilen sözcük ya da sözcük grupları" biçiminde tanımlamıştır. Eker, fiilimsileri isim-fiiller, sıfat-fiiller ve zarf-fiiller olmak üzere üç alt başlık altında incelemiş ve fiilimsilerin yapım eki ve çekim eki görevinde kullanılabileceğini de belirtmiştir **(**Eker, 2010, s. 299).

Tuncer Gülensoy, fiilimsileri *partisip ekleri* ve *gerundium ekleri* olmak üzere iki başlık altında ele almıştır. Ancak partisip eklerine (yani sıfat-fiil eklerine) aynı zamanda isim-fiil eki demiştir. Gülensoy partisip eklerinin geçici ve kalıcı isimler yaptığını, gerundium eklerinin zarf olarak kullanıldığını ifade etmiştir (Gülensoy, 2015, s. 539, 541).

Nesrin Bayraktar, fiilimsileri dile anlatım gücü zenginliği ve kıvraklık sağlamanın yanında anlatılmak isteneni kısa yoldan anlatma olanağı sağlayan, yan cümle kurabilen, bağlaçların yerine geçebilen dil bilgisel unsurlar biçiminde açıklamış; genel olarak isim-fiil, sıfat-fiil ve zarf-fiiller biçiminde üçe ayrılan fiilimsilerin cümle içinde isim, sıfat, zarf gibi isim soylu sözcüklerin görev ve özelliklerini taşıdığını, bir bölümünün isim gibi, bir bölümünün isim ve sıfat gibi, bir bölümünün de zarf gibi kullanıldığını belirterek fiilimsilerin (daha çok zarf-fiil ve sıfat-fiillerin); çoğu zaman bağlaç kullanmadan, anlatımı bölmeden yan cümle kurmayı sağladığını da eklemiştir (Bayraktar, 2018, s. 3)

Bülent Özkan, dilbilgisi kitaplarında fiilimsilerin anlatıma kıvraklık kazandırdığı, anlatılacakları kısa yoldan aktarmayı sağlayarak gereksiz tekrarları önlediği ve aktarılmak istenen düşüncenin iletilmesinde kolaylık sağladığı, ayrıca sözdizimsel olarak cümleleri akıcı ve kolay biçimde birbirine bağladığı konusunda bir anlayış birliği olduğunu söylemiştir (Özkan, 2020, s. 1322)

Zeynep Korkmaz, fiilimsileri *çekimsiz fiiller* başlığı altında ele almıştır ve *çekimsiz fiilleri*, fiil kök ve gövdelerinden belirli eklerle türetilen; ancak, kişi ekleri alarak çekime giremedikleri için, yargı bildirmeyen, dolayısıyla da bitmemiş fiil niteliğinde olan fiiller biçiminde tanımlamıştır (Korkmaz (2022, s. 863).

Birol İpek ve Cemil Özcan ise fiilimsilerin cümlede tek başlarına anlamları olmayan görevli unsurlar olduğunu, fiilimsi eklerinin fiillerin kök ve gövdelerine gelerek yeni sözcük türettiklerini bu yönleriyle yapım eki özelliği taşıdıklarını, eklendikleri fiilleri cümle içerisinde geçici isim, sıfat ve zarf yaptıklarını, ilgili eklerle kurulan geçici kavram münasebetleriyle olumluluk-olumsuzluk ifade edebilen fiillerin isim, sıfat veya zarf olarak temel cümle içerisine yan yargılarla aktarıldığını ve böylelikle karmaşık önermeler içeren cümleler oluşturulabildiklerini ifade etmişlerdir. Ayrıca Fiilimsi eklerini almış unsurların cümlede anlatımı zenginleştiren, anlatıma ayrıntı kazandıran isim, sıfat veya zarf unsurları olarak görev yaptıklarını, eklendikleri fiillerin hareketlilik anlamlarını tamamen yok etmediklerini ancak onları eylem bildirme yönünden zayıflattıklarını, fiillere has olan zaman ve kişi eklerinin fiilimsilerden sonra kullanılmadığını belirtmişlerdir (İpek &Özcan, 2025, s. 3-4).

Türkçede isim, sıfat ve zarf görevinde olan fiilimsiler, diğer başka bazı dillerin aksine kimi zaman bağlaç gibi de kullanılmaktadır. Şöyle ki diğer dillerde (örneğin İngilizce, Almanca vb.) birden fazla cümle birbirine "müstakil" olarak (relative clouse denilen who, which, that vb. sözcük düzeyinde) bağlaçlarla bağlanmaktadır. Türkçede ise cümleler birbirine bağlaçlarla bağlanabildiği gibi kimi zaman fiilimsilerle de bağlanabilmektedir. Yani fiilimsiler, iki cümleyi bağlayan bağlaç işlevi de görmektedirler.

Bu çalışmada Cumhuriyet Dönemi eserlerinde fiilimsi eklerinin kullanımı üzerinde durulmuştur. Çalışmaya malzeme olarak Orhan Midhat Barbaros'un 1925 yılında yayınlanan *Meçhul Kan* adlı eseri alınmıştır. Orhan Midhat Barbaros (1894-1964) yirminci yüzyılın (Cumhuriyet döneminin) avukat kimliğiyle öne çıkan ilk romancılarındandır. Orhan Midhat Barbaros'un romancılığı, yaşamından beslenmiştir (Solmaz, 2018, s. 2). Farklı tür (roman, öykü vb.) ve alanda yazdığı eserler (hukuk, toplum, iktisat vb.) yazıldıkları döneme ışık tutmaları bakımından oldukça değerlidir (Solmaz, 2018, s. 18) Orhan Midhat Barbaros eserlerinde aşk, evlilik, değişen değerler, gayrimeşru cinsellik ve milli duygular gibi konuları işlemiştir (Solmaz, 2018, s. III). Toplumu eğitme amacı güttüğü için sade ve anlaşılır bir dil kullanmıştır. 1925 yayımlanan *Meçhul Kan* adlı eseri ise, Cumhuriyet'in ilk yıllarında kaleme alınmış bir Osmanlı eleştirisidir. Eserde makamına âşık bir paşanın oğlu olan Celil ile II. Abdülhamit'in kızı Sultan Mahinur'un aşkı konu edinmiştir. Bu eserde oldukça anlaşılır bir dil kullanan, düz ve basit cümleler kullanmaya özen gösteren Orhan Midhat Barbaros, fiilimsilerin kullanımına da ağırlık vermiştir. Buna göre eserde fiilimsilerden isim-fiil, sıfat-fiil ve zarf-fiillerin yoğun olarak kullanıldığı dikkati çekmektedir. Ancak yazar eserinde fiilimsi eklerinden *-mA* ve *-mAk* isim-fiil eki; *-AcAk, -An, -DIk/-DUk, -mIş/-mUş* sıfat-fiil eki ve *-A, -ArAk, -DIkçA/-DUkçA, -IncA/-UncA, -ken, -mAdAn, -Ip/-Up, -r -mAz* zarf-fiil eklerini kullanmıştır. Çalışmada da öncelikle bu isim-fiiller, sıfat-fiiller ve zarf-fiiller hakkında bilgi verilmiş ardından bunların Cumhuriyet dönemindeki kullanımları ve kullanım sıklıklarına değinilmiştir. Buna göre eserde geçen fiilimsi ekleri ve örnekleri şöyle gösterilebilir:

ARAŞTIRMA VE BULGULAR

1. Meçhul Kan Adlı Metinde Yer Alan İsim-Fiil Ekleri

Güncel Türkçe Sözlük 'te isim-fiil "ad-fiil" biçiminde geçmektedir (URL-2).

İsim-fiillerin temel görevleri, fiillerin isimlerini yapmaktır. Fiillerin kök ve gövdelerine getirilen isim-fiil ekleriyle bunlar isme dönüştürülür ve diğer sözlük birimlerinin cümle içerisinde yüklendiği özne, nesne, dolaylı tümleç, yüklem gibi bütün görevleri yüklenebilirler. İsim-fiiller, *-mAk, -mA* ve *–Iş* ekleriyle kurulur. Bunlar fiildeki oluş ve kılışı bir iş adına dönüştürme özelliği taşırlar, her türlü olumlu, olumsuz fiil kök ve gövdeleriyle, çatı ekleri almış fiillere de getirilebilir (Bilgegil, 2009, s.234).

İsim-fiil eki almış sözcükler bir ismin üstlenebileceği her türlü görevi yapabilirler (Abdıu, 2012, s.3). Eserde geçen isim-fiil ekleri şunlardır:

1.1. -mA İsim-Fiil Eki ile Kurulanlar

Alma, buluşturma, çekilme, çekmey, çıkarma, çökme, didinme, dönme, durma, duyma, düşünme, edilme, eglenme, etmey, ettirme, gezme, girilme, görme, havlama, haykırışma, hazırlanma, inleme, işitilme, kaldırma, kalkma, kaplama, karışma, karıştırma, kızarma, olma, olunma, oturma, oynama, oynatma, ölme, sayma, sıçrama, söylenme, titreme, uzatma, varma, verme, yadırgama, yaşama, yayma, yumuşatma

1.2. -mAk İsim-Fiil Eki ile Kurulanlar[74]

Açmak, aġlamak, almak, anlamaḳ, anlatmak, atlamak, atmak, bakılmak, bakmak, bırakmak, çekiştirmek, çıkmak, dilenmek, dinlemek, dolaşmak, dönmek, duyurmamak, düşünmek, eglenmek, etmek, ettirmek, ezilmemek, ezmek, geçmek, getirmek, getirmek, gezmek, giyinmek, göndermek, görebilmek, görmek, görmemek, görünmek, göstermek, haykırmak, ilerlemek, işitmek, ittirmek, kaçırmak, kaldırmak, kalkışmak, kalmak, kapamak, karartmak, karıştırmak, katlanmak, kayırmak, kesmek, kızdırmak, konuşmak, koparmak, koparmak, koymak, kurtulmak, mahv etmek, nişanlamak, okumak, okutmak, olmak, oturmak, oynamak, ölmek, parçalamak, sallanmak, savmak, selamlamak, sevdirmek, sevilmek, sevmek, seyretmek, sokulmak, söylemek, susturmak, uġraşmak, uzatmamak, vermek, vurmak, yakalamak, yaptırmak, yaşamak, yaşatmak, yükselmek.

[74] Bu metinde yalnızca bir sözcükte *-Iş* isim-fiil ekinin kullanıldığı görülmüştür: *sürükleniş*

2. Meçhul Kan Adlı Metinde Yer Alan Sıfat-Fiil Ekleri

Güncel Türkçe Sözlük'te sıfat-fiil "fiilden -acak, -an, -ası, -dık, -maz, -mış, -r ekleriyle yapılan, sıfat olarak kullanılıp zaman kavramı taşıyan ve -ma- ekiyle olumsuz biçimi yapılabilen kelime; ortaç, partisip" biçiminde tanımlanmaktadır (URL-3).

Sıfat-fiil eki almış sözcükler cümlede sıfat gibi kullanılabilirler, adlaşarak isim gibi kullanılabilirler, bağlaçlara ihtiyaç kalmadan yan cümleler kurarak birleşik cümleler oluşturma görevini üstlenirler; ayrıca sıfat tamlamalarının sıfatı olarak da görev yapabilirler (Abdıu, 2012, s. 3).

Sıfat-fiiller, fiillerin kök ve tabanlarına -An, -()r, -Ar, -dIk, -mAz, -mIş, AcAk, -mAdIk, -AsI sıfat-fiil ekleri getirilerek yapılırlar. Sıfat gibi kullanılabilen fiil şekilleridir. Hem fiil hem de sıfat özelliği gösterirler. Sıfat-fiiller isim gibi işlem görürler, dolayısıyla iyelik, çokluk ve isim çekim eklerini alabilir, diğer isimler gibi özne, nesne, tümleç görevlerini yerine getirebilirler. Hareket ve zaman ifade ederler, olumlu ve olumsuz şekilleri yapılabilir (Gencan, 1978, s. 195).

Sıfat-fiil, fiilin zamana bağlı olarak kavramını sıfatlaştıran bir şeklidir. Zaman anlatımı taşımaları yönünden ad-fiillerden ayrılırlar (Banguoğlu, 2011, s. 422).

Eserde geçen sıfat-fiil ekleri şunlardır:

2.1. AcAk Sıfat-Fiil Eki ile Kurulanlar

'arz edecek bir şeyi, adım atacak yer, ağıza alınacak şeyler, dağıtacakları hiç bu para, gönlümü oyalayacak şeyler, işine yarayacak sözler, kafası koparılacak yılanlar, kımıldayamayacak kadar mecalsiz, mevlüt alayında görecek başka şey, vergi verecek hāl.

2.2. -An Sıfat-Fiil Eki ile Kurulanlar

'akis eden, 'akisler yapan, açan, akan, akıtan, anlaşılan, anlatan, asılan, atan, ayıran, bakan, bakınan, baş döndüren, başlayan, beliren, benzeyen, bıkmayan, bilen, bilinen, bulunan, bunalan, büyüyen, ciddileşen, çakan, çarpan, çıkan, çöken, çukurlaşan, dağıtan, dehşet veren, delirten, denilen, dikilen, dilberleşen, dillerde dolaşan, dinleten, dinleyen, dizilen, doğan, dolaşan, dolduran, dökülen, duran, ebrulaşan, esirgemeyen, fışkıran, geçen, gelen, gelmeyen, gezen, giden, giren, giyen, giyinen, görünen, görünmeyen, göz kamaştıran, gözü alan, gülümseyen, hasıl olan, haykıran, hitap eden, huysuzlanan, hücum eden, iç sıkan, ikileten, ilişen, incelen, inen, inleyen, isteyen, kaçan, kaçırmayan, kaçışan, kafa tutan, kalan, kamaştıran, kaplayan, kararan, karışan, karşı duran, karşılaşan, katan, kayıb olmayan, kaynaşan, kaynatan, kazanan, kesilen, kesilmeyen, koşan, kuşatan, mefkuresi olmayan, meydana çıkan, morlaşan, mühimleşen, müyesser olmayan, okşayan, okunan, olan, olmayan, oturan, oyalayan, ölen, ötüşen, parlayan, peyda eden, saçan, sallanan, saplanan, saran, secde eden, serpen, seven, sıçrayan, sıralanan, sıyrılan, silen, söndüren, şaklayan, takan, takati kalmayan, taşan, taşıyan, tatdırmayan, tavana degen, tesadüf eden, titreten, toplayan, tutuşturan, uçan, umursayan, unutturan, usanmayan, uyanan, uyuyan, uzanan, ürperten, varılmayan, veren, verilen, yakan, yaklaşan, yalayan, yanan, yaşatan, yatışmış olan, yayılan, yetiştiren, yıkılan, yıkılmayan, yürüyen.

2.3. -DIk Sıfat-Fiil Eki ile Kurulanlar

aç çıplak bıraktığı, ajurlarının saklayamadığı, ara sıra gözlerini kırpmasından uyumadığı, aydınlatamadığı muzlim ve uzun salon köşeleri, baḥs etmedigin bir yer ḳalmadı, bendegan dediğiniz, bir çift kaplan gibi durduġu yer, boğazlarını besledikten sonra, ceplerini doldurduktan sonra, hayatımızın baharını yaşadıktan sonraki günlerimiz, her gün gördügümüz şeyler, kal dedikleri yerde, kendi yüzünden uġradığım felaketi, merak hissettigi bu aşk, omzuna yapıştığını, oturduġu kanepe, oturduġu yer, saltanatının yetiştirdigi bir nev' nebat gibi gümüşten dalları, taşıya taşıya yitiremediği insanlar, tıpkı alayda olduġu gibi 'asker, verd-i zeban ettiği.

2.4. -mIş/mUş Sıfat-Fiil Eki ile Kurulanlar

bakir, hırpalanmış sine, birbirinin arkasına sıralanmış … lastik tekerlekler, büyük ve ağır bir yükün altından çıkmış hafiflik, çaresiz kalmış vaziyet, derileri kemiklerine yapışmış, benzi sararmış bir sürü kadın, el ele tutuşmuş iki kız, entarilerinin üstünden henüz kopmuş memeler, ezberlenmiş bir dua, faytonun içinde geriye çekilmiş bir delikanlı, hiddetinden morarmış bir sima, içinde şevketli korkudan rengi uçmuş gibi şaşkın bir hāl, meydanda bırakmış yastık, müphem işaretler ve nazarlar yatışmış üzere, o gün fabrikadan çıkmış kadir, parke taşı döşenmiş kaldırımlar, sarı meşinden silahlıklarına

sokulmuş parlak kısa turalar, sinirden taş kesilmiş buz gibi iki el, taç şeklinde işlenmiş altın yaldızlı fenerler, unutmuş gibi gözler, üstüne serpilmiş sarışın saçlar.

3. Meçhul Kan Adlı Metinde Yer Alan Zarf- Fiiller

Güncel Türkçe Sözlük'te zarf-fiil "fiilden -a, -arak, -dıkça, -ınca, -ıp, -madan vb. eklerle yapılan, zarf olarak kullanılan kelime; ulaç, bağ-fiil, sıla sigası" biçiminde geçmektedir (URL-4).

Zarf-fiiller cümlede zarf tümleci yapma görevinde kullanırlar, yan cümle kurarak birleşik cümle oluşturabilirler, yardımcı fiiller ve ek fiil yardımıyla yüklem olarak da kullanılabilirler. Zarf-fiiller cümlede, ana cümlenin ya da yan cümlenin yükleminin belirticisi durumunda kullanılırlar (Abdıu, 2012, s.3).

Zarf-fiillerin bir diğer önemli görevleri yardımcı fiillerin önüne gelerek tezlik, yeterlilik, sürerlilik ve yaklaşma anlamı veren kurallı birleşik fiiller yapmaktadır (Bayraktar, 2004, 6)

Zarf-fiiller hareket hâli ifade eden fiil biçimleridir. Çekim eki almazlar. Fillerin zarf biçimlerini oluşturduklarından zarf-fiil olarak isimlendirilirler.

Hareket halinden başka devamlılık, zaman ve sebep gibi zarf işlevlerini de ifade ederler. Bunlar zarf-fiil cümleleri olarak temel cümleyi zaman, sebep, tarz, şekil ve şart gibi özellikler açısından tamamlarlar (Zengin, 2017, s. 156).

Eserde yer alan zarf-fiil ekleri şunlardır:

3.1. -A Zarf- Fiil Eki ile Kurulanlar

ağlaya ağlaya, anlata anlata, ayıla bayıla, bağıra bağıra, bağıra çağıra, çeke çeke, çekine çekine, dalğalana dalğalana, diye, diye diye, dolaşa dolaşa, döne döne, düşüne düşüne, gerile gerile, göre göre, hayķıra hayķıra, ķana ķana, ķatıla ķatıla, ķıvrıla ķıvrıla, ķoķlaya ķoķlaya, ķorķa ķorķa, ķoşa ķoşa, oķuya oķuya, ödeye ödeye, öpe öpe, şallaya şallaya, sendeleye sendeleye, seve seve, şıçraya şıçraya, şoluya şoluya, söyleye söyleye, sürüklüye sürüklüye, şaķlata şaķlata, şişire şişire, ţaşıya ţaşıya, ţırmalaya ţırmalaya, uzata uzata, vura vura, yalaya yalaya, yiye yiye.

3.2. -ArAk Zarf- Fiil Eki ile Kurulanlar

açarak, alarak, baķarak, bayıltarak, bırakarak, bilerek, bilmeyerek, bozarak, bükerek, çatarak, çekerek, çıķararak, çırparak, dikerek, diyerek, dolaştırarak, dönerek, düşünerek, egerek, egilerek, emirler vererek, gezinerek, görüşerek, göstererek, götürerek, göz yumarak, gülerek, gülümseyerek, güvenerek, ḥissederek, ḥisse-i ġurūr çıķararak, ḥüküm ederek, ışırarak, içerek, içini çekerek, istiżāḥ götürerek, işāret ederek, ķaldırarak, ķavrularak, ķavuşturarak, kaybederek, ķaynayarak, ķazıyarak, ķırarak, ķırparak, kıpırdatarak, ķollarını ķavuşturarak, ma'rūż ķalarak, nefeslerini ţutarak, olarak, ovuşturarak, oynayarak, şallayarak, şarşılarak, şatılarak, şayarak, serperek, sıçrayarak, şıķarak, şırıtarak, silkinerek, şoğuķ alarak, şoķularak, şomurtarak, sözünü keserek, süzerek, tepinerek, titreyerek, ţutarak, uzatarak, ümit ederek, va'żiyetler alarak, vurarak, yapışarak, yumarak, ziflenerek.

3.3. -D(I)KçA/-D(U)KçA Zarf- Fiil Eki ile Kurulanlar

bulduķça, dedikçe, fırsat bulduķça, geldikçe, gittikçe, gördükçe, ḥayķırdıķça, ilerledikçe, iẓḥār ettikçe, ķaldırdıķça, karşı ķarşıya geldikçe, ķarşılaştıķça, oķuduķça, titredikçe, ufaldıķça, yaķlaştıķça.

3.4. -IncA/-UncA Zarf- Fiil Eki ile Kurulanlar

almayınca, anlayınca, arż edilince, atlayınca, çıķınca, gelince/girince(ye), görünce, ķalmayınca, ķudurtunca(ya) ķadar, öfkesini alamayınca, ölünce, patlayınca(ya) ķadar, ţutulunca, varıncaya ķadar.

3.5. -ken Zarf- Fiil Eki ile Kurulanlar

aķıtırken, alırken, çabalarken, çekerken, çevirirken, çıķarken, çırpınırken, çocuķ iken, dağıtırken, dalgalanırken, dönerken, garķ ederken, geçerken, gezerken, girerlerken, gülerken, gülümserken, icat ederken, iliştirirken, ķapanırken, ķaparken, ķaranlıķ iken, ķovalarken, parçalarken, raķs ederken, recâl-i devlet ederlerken, şavururken, selamlarken, sorgularken, söylerken, sürünürken, veremezken, yüzerken.

3.6. -mAdAn Zarf- Fiil Eki ile Kurulanlar

almadan, anlamadan, anlatmadan, bakamadan, baḳmadan, basmadan, batırmadan, beklemeden, bulmadan, çevirmeden, çıḳarmadan, dinlenmeden, dinmeden, durmadan, düşünmeden, görmeden, ḫaberi olmadan, ḫırpalanmadan, ḥissettirmeden, içmeden, ḳırpmadan, ḳonuşmadan, ölmeden, söylemeden, söyleyemeden, vermeden, yazmadan, yemeden.

3.7. -(I)p/-(U)p Zarf- Fiil Eki ile Kurulanlar

Açılıp, açıp, ağlaşıp, 'aklına gelip, alıp, anlamayıp, baḳıp, baḳıp baḳıp, bıraḳıp, bilip, bitip, bulup, bulup buluşturmak, buluşturup, buluşup, buyurup, çekinip, çekip, çıḳarıp, çıkıp, deyip, diḳḳat edip, durup, düşünüp, egilip, ellerini ḳavuşturup, erişip, getirip, gidip, girip, görüp, gülüp, indirip, ḳabarıp, ḳaldırıp, ḳıpırdatıp, ḳışılıp ḳabarıp, ḳoḳlayıp, ḳoparıp ḳoparıp, ḳopup, ḳoşup, ḳoyup, ḳurtulup, olup, ovuşturup, rızḳından kesilip, ṣallayıp, sıçrayıp, ṣıvazlayıp, söylemeyip, söyleyip, ṭoplanıp, ṭoplayıp, ṭutturup, ṭutup, uzanıp, uzatıp, yıḳayıp, yiyip içip.

3.8. -r -mAz Zarf-Fiili ile Kurulanlar

alır almaz, anlar anlamaz, atlar atlamaz, başlar başlamaz, duyar duymaz, gelir gelmez, görür görmez, iner inmez, ister istemez.

SONUÇ

Fiilimsiler, Türkçeye anlatım gücü ve kıvraklığı kazandıran, anlatılanları kısa yoldan aktarmayı sağlayarak gereksiz tekrarları önleyen, aktarılmak istenen düşüncenin iletilmesinde kolaylık sağlayan ve sözdizimsel olarak tümceleri akıcı, kolay biçimde birbirine bağlayan eklerdir. Fiilimsiler kullanım sıklığı bakımından Türkçede önemli bir yer tutmaktadır.

Türkçede isim, sıfat ve zarf görevinde olan fiilimsiler, diğer başka bazı dillerin aksine kimi zaman bağlaç gibi de kullanılmaktadır.

Bu çalışmada Cumhuriyet Dönemi eserlerinde fiilimsilerin kullanımı üzerinde durulmuştur. Çalışmada öncelikle isim-fiiller, sıfat-fiiller ve zarf-fiiller hakkında bilgi verilmiş ardından bunların Cumhuriyet dönemindeki kullanımları ve kullanım sıklıklarına değinilmiştir. Çalışmaya malzeme olarak Orhan Midhat Barbaros'un 1925 yılında yayınlanan *Meçhul Kan* adlı eseri alınmıştır. Buna göre, eserde isim-fiil eklerinden *-mA, -mAk, -Iş*, sıfat-fiil eklerinden *-AcAk, -An, -DIk/-DUk, -mIş/-mUş* ve zarf-fiil eklerinden ise *-A, -ArAk, -DIkçA/-DUkçA, -IncA/-UncA, -ken, -mAdAn, -Ip/-Up, -r -mAz* eklerinin yaygın olarak kullanıldığı görülmüştür. Bu da Cumhuriyet Dönemi'nde başka bazı fiilimsi ekleri olmasına rağmen sözü edilen fiilimsi eklerinin daha çok tercih edildiğini göstermektedir. Bu durum dönemsel özellikler yanında Cumhuriyet Dönemi eserlerini oluşturan yazar/yazarların kendi tercihleriyle de açıklanabilmektedir.

Meçhul Kan adlı metinde fiilimsi eki alan 617 sözcük tespit edilmiştir. Bunlardan 132'sini (47'si *-mA*, 84'ü *-mAk* ve 1'i *–Iş)* isim-fiil ekleri; 206'sını (10'u *-AcAk*, 155'i *-An*, 21'i *-DIk*, 20'si *-mIş/mUş)* sıfat-fiil ekleri; 278'ini (40'ı *-A*, 77'si *-ArAk*, 16'sı *-D(I)KçA/-D(U)KçA*, 14'ü *-IncA/-UncA*, 34'ü *-ken*, 29'u *-mAdAn*, 59'u *-(I)p/-(U)p* ve 9'u *-r –mAz)* zarf- fiil ekleri oluşturmaktadır. Bu da Cumhuriyet dönemi eserlerinde fiilimsi eklerinden, genel olarak, en çok zarf-fiillerin ardından sıfat-fiil ve isim-fiillerin kullanıldığını göstermektedir. Bunların içinde ise zarf-fiil eklerinden *–ArAk,* sıfat-fiil eklerinden *-AcAk* ve isim-fiil eklerinden *-mak* ekinin daha çok kullanıldığını/tercih edildiği görülmektedir.

Dolayısıyla Cumhuriyet dönemi eserlerinde, cümlelerin birbirine kimi zaman ayrı ayrı, kimi zaman (ama, ancak, çünkü, fakat, ki şöyleki vb.) bağlaçlarla, kimi zamanda fiilimsilerle bağlandığı dikkati çekmektedir.

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DIGITAL STATE CAPACITY AND THE INSTITUTIONALIZATION OF ARTIFICIAL INTELLIGENCE GOVERNANCE A COMPARATIVE ANALYSIS OF DIGITAL PUBLIC ADMINISTRATION CAPACITY

DİJİTAL DEVLET KAPASİTESİNİN YAPAY ZEKÂ YÖNETİŞİMİNİN KURUMSALLAŞMASINI ŞEKİLLENDİRMESİ VE DİJİTAL KAMU YÖNETİMİ KAPASİTESİ DÜZEYİNİN KARŞILAŞTIRMALI ANALİZİ

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ÖZET
Yapay zekânın kamu yönetimine entegrasyonu çoğu zaman yalnızca yeni bir teknolojiye uyum sağlama süreci olarak ele alınmaktadır. Bu yaklaşım, yapay zekâ yönetişiminin mevcut dijital devlet altyapısından bağımsız biçimde gelişebileceğini örtük olarak varsayar. Bu çalışma, yapay zekâ yönetişiminin kurumsallaşmasını, daha önce birikmiş dijital kamu yönetimi kapasitesi üzerinde yükselen yeni bir yönetsel aşama olarak kavramsallaştırmaktadır. Temel hipotez, başlangıçtaki dijital devlet kapasitesi daha yüksek olan ekonomilerin izleyen dönemde yapay zekânın etik ve yönetsel kullanımını daha ileri düzeyde kurumsallaştıracağıdır.
Ampirik analiz, Dünya Bankasının GovTech Olgunluk Endeksi'nin 2022 ve 2025 sürümleri eşleştirilerek oluşturulan 197 ulusal ekonomiden oluşan karşılaştırılabilir bir örnekleme dayanmaktadır. Bağımsız değişken 2022 GTMI toplam puanı, bağımlı değişken ise 2025'te yapay zekâ alanında etik ilkelerin uygulanma durumunu gösteren ve üç düzeyde yeniden kodlanan göstergedir: düzenlemenin bulunmaması, planlama veya taslak hazırlama aşaması ve kurumsallaşmış düzenleyici çerçeve. Spearman sıra korelasyonu pozitif, istatistiksel olarak anlamlı ve sağlam bir ilişkiye işaret etmektedir ($\rho = 0{,}733$; $p < 0{,}001$; %95 bootstrap güven aralığı [0,660; 0,791]). Başlangıç kapasitesi bakımından en alt çeyrekte yer alan 50 ekonominin yalnızca birinde etik ilkeler kurumsallaşmışken, en üst çeyrekteki 49 ekonominin 40'ında kurumsallaşma sağlanmıştır. Değişkenlerin farklı zaman noktalarında ölçülmesi olayların zamansal sıralamasını güçlendirse de gözlemsel tasarım, ikincil verilerin aynı kaynaktan gelmesi ve ölçülmeyen kurumsal ortak değişkenler katı bir nedensel yorum yapılmasına izin vermemektedir.
Bulgular, kamu sektörünün yapay zekâyı bütünleştirmeye hazırlığının yalnızca hesaplama kapasitesine veya yazılım satın alımına indirgenemeyeceğini göstermektedir. Bu hazırlık; stratejik planlama, kurumlar arası eşgüdüm, veri yönetişimi, düzenleyici altyapı ve yönetsel yetkinliklerde birikmiş sermaye tarafından belirlenmektedir. Dolayısıyla yapay zekânın kurumsal yönetişimi, ülkeler arasındaki kurumsal farklılıkları kendiliğinden ortadan kaldıran teknolojik bir olgu olarak değil, yerleşik kurumsal farklılaşma üzerinde yeniden üretilen ek bir devlet kapasitesi katmanı olarak değerlendirilmelidir.
Anahtar kelimeler: Dijital devlet kapasitesi; yapay zekâ yönetişimi; kurumsal dönüşüm; dijital kamu yönetimi; karşılaştırmalı kamu yönetimi.

ABSTRACT
The integration of artificial intelligence into public administration is often framed as the adoption of a new technology. That view carries an implicit assumption that AI governance can develop independently of existing digital state capacity. This study treats the institutionalization of AI governance as a new administrative stage built on previously accumulated digital public administration capacity. It therefore expects economies with higher initial digital state capacity to institutionalize the ethical and administrative use of AI more extensively in the following period.
The empirical analysis matches 197 economies across the 2022 and 2025 editions of the World Bank GovTech Maturity Index. The independent variable is the 2022 GTMI score. The dependent variable records whether AI ethics guidelines in 2025 were absent, planned or drafted, or institutionalized.

Spearman's rank correlation indicates a strong positive association (ρ=0.733; p<0.001; 95% bootstrap confidence interval 0.660-0.791). Only one of the 50 economies in the lowest baseline-capacity quartile had institutionalized guidelines, compared with 40 of the 49 economies in the highest quartile. Measuring the variables at different points in time strengthens temporal ordering, but the observational design, common data source, and unmeasured institutional factors do not support a causal interpretation. The findings move the discussion of AI readiness beyond computing infrastructure and software acquisition. Institutionalization appears to rest on accumulated capabilities in strategy, coordination, data governance, law, and public administration. AI governance should therefore be understood as an additional layer of state capacity that develops on top of existing institutional differences rather than as a technological field that automatically narrows them.

Keywords: Digital state capacity; AI governance; institutional transformation; digital public administration; comparative public administration.

INTRODUCTION

Public authorities increasingly use artificial intelligence algorithms across a range of applications, including the automated classification of citizen requests, profiling and risk scoring, optimization of budget allocation, and personalization of public services. These uses, however, require an organizational and institutional framework that extends well beyond the installation of technical tools. An operational AI system cannot become a legitimate instrument of public administration unless the purposes and permissible limits of data processing, protocols for model validation and auditing, mechanisms for explaining decisions to affected parties, and administrative and judicial avenues of appeal are clearly regulated. The analytical review by Wirtz, Weyerer, and Geyer (2019) shows that debate on AI in the public sector is not confined to optimistic expectations about operational efficiency but also addresses organizational, legal, and ethical concerns.

The development of the research problem in the academic literature likewise calls for this multidimensional perspective. According to the systematic review by Zuiderwijk, Chen, and Salem (2021), much of the research on AI governance in the public sector remains exploratory and explanatory and focuses on narrow fields of application. By contrast, rigorous cross-national empirical studies explaining the organizational consequences of technological change remain seriously underdeveloped. It is therefore insufficient merely to establish that a state has issued a declaratory document on AI ethics. Such measures must be related to the administrative environment in which they emerge, an environment grounded in prior digital infrastructure and institutional capacity. This article seeks to address this theoretical gap through a temporally ordered cross-national comparative analysis.

International guidance has clearly articulated these governance requirements. UNESCO's Recommendation on the Ethics of Artificial Intelligence links the primacy of fundamental human rights, privacy, transparency, institutional accountability, and human oversight inseparably to their domains of application (UNESCO, 2022). Yet publishing declaratory principles is not equivalent to embedding them in public decision-making. Jobin, Ienca, and Vayena (2019) show that although global ethics guidelines share a common core of values, national approaches to interpretation and legal enforcement vary considerably. Busuioc (2021) likewise emphasizes that algorithmic accountability extends beyond the development of a technically interpretable model and depends on stable institutions of responsibility together with a coherent system of legal and supervisory relations.

In this context, digital state capacity is a decisive institutional precondition. Digital public administration is not limited to the aggregate volume of existing electronic services; it encompasses shared infrastructure, interoperable platform environments, data governance systems, human-centered service design, and institutional arrangements for sustainable transformation. The OECD's methodological framework defines digital government maturity along six interconnected dimensions: digital by design, data-driven, government as a platform, open by default, user-driven, and proactive service delivery (OECD, 2020). The E-Leaders Handbook states that these dimensions must be supported by an appropriate institutional model, public policy instruments, and adaptation to national context (OECD, 2021). Consequently, even drafting and reaching agreement on a basic AI ethics guideline depends on horizontal relationships previously institutionalized among legal experts, data architects, operational units, and central government coordination bodies.

Conceptual research on digital transformation strengthens the explanatory value of the cumulative-capacity thesis. Mergel, Edelmann, and Haug (2019) conceptualize transformation not as the procurement of disconnected technological solutions but as a fundamental restructuring of administrative arrangements, organizational culture, and the architecture of cross-sectoral interaction. Within this paradigm, AI regulation and governance do not constitute a process that begins from scratch independently of accumulated digital state capacity. They form a qualitatively new institutional layer built on functioning data assets, interoperability standards, bureaucratic expertise, and channels of coordination. Even so, comparative empirical research testing this dependence at the macro level with longitudinal panel data remains fragmented.

The research question is whether national economies with greater digital public administration capacity in 2022 had institutionalized principles governing the ethical use of AI to a more advanced degree by 2025. The research hypothesis posits a positive, monotonic, and statistically significant relationship between the two indicators. The study operationalizes this relationship not within a strict causal-effect paradigm but as an empirically observable implication of a cumulative model of state capacity. This distinction is critical because per capita income, regional waves of policy diffusion, national administrative traditions, and the intensity of relations with international organizations may simultaneously shape both general digital capacity and the dynamics of regulatory production in the field of AI.

METHODS AND EMPIRICAL FINDINGS

Research Design

The empirical analysis draws on the World Bank's 2022 and 2025 GovTech Maturity Index datasets. The GTMI combines four principal components: the operation of core government systems and integrated digital infrastructure, the maturity of online services, the development of digital citizen engagement, and institutional enablers of digitalization, including strategy, legislation, innovation, and human capital. The composite index ranges from 0 to 1 (World Bank, 2022; Vasconcelos et al., 2025). It was designed solely as a diagnostic measure of the public sector's technological and regulatory maturity. Methodologically, it should therefore not be interpreted as a comprehensive ranking of overall government effectiveness, the quality of democratic institutions, or the socioeconomic performance of public policy.

The 2022 public dataset, which initially covered 198 economies, was matched to the 2025 records using the World Bank's unique country identifiers. Because no verified numerical GTMI value was available for Nicaragua in 2025, the balanced panel consists of 197 national jurisdictions. No missing-value imputation was performed. The total 2022 GTMI score serves as the indicator of baseline capacity. The outcome variable is indicator I-41 in the 2025 database. It evaluates the implementation status of AI ethics principles on a three-level discrete scale: 0 indicates the absence of any regulatory guidance, 1 denotes the strategic planning or drafting stage, and 2 represents an institutionalized regulatory and legal regime. Although the indicator records the institutional fact that a regulatory framework exists, it does not directly measure actual organizational compliance, the budgets of supervisory bodies, or the scope of enforcement mechanisms (World Bank, 2023, 2025).

Table 1 Operationalization of Variables and Methodological Limitations

Variable	Scale and unit of measurement	Analytical limitations
Baseline digital state capacity	2022 GTMI score from 0.000 to 1.000	A composite index of technological maturity; it is not equivalent to the overall effectiveness of public authority.
Ethical regulation of artificial intelligence	2025 I-41 indicator: 0 absent, 1 draft or plan, 2 institutionalized	Measures the existence and legal status of a formal document; it does not capture the intensity of oversight or the quality of implementation.

Because the dependent variable is ordinal and contains numerous tied ranks, Spearman's rank correlation coefficient was selected as the principal statistical measure. Kendall's tau-b was calculated as an additional robustness check. Confidence intervals were obtained from 10,000 country-level nonparametric bootstrap resamples, and two-sided statistical significance was verified with a 19,999-permutation test. The 2022 distribution was also divided into four approximately equal quartiles for comparative cross-tabulation. To ensure full reproducibility, the random-number generator seed was fixed at 20260920.

Empirical Findings

Among the 197 jurisdictions, 84 economies had no ethical regulation governing the use of AI. A further 36 were at the conceptual design or legislative drafting stage, while 77 had established an institutionalized regulatory regime. The mean 2022 GTMI scores for these groups were 0.353, 0.534, and 0.781, respectively. Their medians displayed a similar monotonic pattern: 0.304, 0.515, and 0.796. As baseline capacity increased, the probability that a jurisdiction would fall into the highest regulatory category rose markedly.

Table 2 Distribution of Ethical Regulation Levels by 2022 GTMI Quartile

2022 GTMI quartile	No ethical regulation 0	Draft or planning stage 1	Institutionalized level 2	Total	Institutionalization rate
Bottom quartile	45	4	1	50	2.0%
Second quartile	24	20	5	49	10.2%
Third quartile	12	6	31	49	63.3%
Top quartile	3	6	40	49	81.6%
Sample total	84	36	77	197	39.1%

The table indicates pronounced structural polarization. Only six of the 99 economies in the bottom two quartiles had institutionalized AI ethics, compared with 71 in the top two quartiles. Accumulated capacity is not, however, determinative in an absolute sense; it is neither a necessary nor a sufficient condition. Three countries in the top quartile had yet to establish a regulatory framework, while one instance of institutionalization appeared in the bottom quartile. Governments' sovereign policy agendas and discretionary legal choices therefore cannot be mechanically reduced to their overall level of digital maturity.

Spearman's rank correlation coefficient was 0.733 ($p < 0.001$; 95% bootstrap confidence interval [0.660, 0.791]). Kendall's tau-b, calculated as a robustness measure, was 0.591. Both statistics confirm a positive, stable, and statistically reliable relationship between baseline digital public-sector capacity and the subsequent institutionalization of AI governance. The correlation between total GTMI scores in 2022 and 2025 was also 0.925 (95% confidence interval [0.900, 0.942]). The persistence of countries' relative positions over the three-year period provides empirical support for the cumulative character of state capacity.

Discussion of Findings

Although the empirical evidence supports the hypothesis, it does not directly identify the micro-level mechanisms underlying the observed relationship. One possible mechanism is that high-capacity states have already accumulated institutional assets such as systematic data records, interoperability protocols, qualified information technology specialists, and channels of interagency interaction. This foundation enables the rapid development of sector-specific rules for AI. A second mechanism concerns the overall regulatory coherence of the state apparatus. An administration capable of managing digitalization strategically and through regulation can establish oversight, accountability, and allocations of

responsibility for emerging technological risks at lower transaction costs. A third mechanism involves policy diffusion: countries within similar income groups or regional clusters may adopt and implement international reference frameworks concurrently.

Radu's (2021) comparative analysis of national AI strategies emphasizes that regulatory institutions are constructed through highly diverse forms of triangular interaction among the state, the private sector, and expert epistemic communities. This variation means that documents carrying similar ethical labels should not be treated as equivalent in either legal force or practical enforceability. Similarly, Busuioc's (2021) account of accountability maintains that public responsibility cannot be delegated to an algorithm's internal mathematical parameters. Because the I-41 indicator used in this analysis abstracts from the qualitative depth of implementation, the observed relationship confirms only the formal institutionalization of regulatory measures, not the quality of institutional governance.

Assessing accountability through the framework of public justification makes this limitation even more apparent. According to Binns (2018), the legitimacy of an algorithmic administrative action cannot be reduced to the abstract technical interpretability of a neural-network architecture. Legitimacy depends on the state's capacity to present the reasons for a decision to citizens in a form that is explainable, comprehensible, and open to procedural challenge. The adoption of a declaration therefore has no automatic connection to a functioning accountability mechanism. Unless appeal bodies, standards for recording decisions, supervisory powers, and legal duties to correct algorithmic errors are institutionally defined, a regulatory text cannot become a legal norm that effectively constrains administrative discretion. The institutionalization captured by the GTMI indicator is a critical but insufficient threshold condition for accountability.

Features of the research design may also have partly increased the strength of the empirical relationship. Both the 2022 GTMI and the 2025 I-41 indicator are aggregate measures compiled by World Bank units through a combination of government surveys and open sources. Governments' ability to report institutional mechanisms in detail covaries with their actual administrative capacity. In addition, the 2025 methodology incorporated the AI ethics block into the institutional enablers component. Comparing the dependent variable with the total score from the preceding period, 2022, minimizes direct mathematical overlap, but some conceptual overlap remains. The final result has therefore been interpreted appropriately as a lagged association.

Despite these limitations, the observed regularity has a clear implication for public policy. Developing a functional regulatory framework for AI does not require extraordinarily expensive computing capacity or sovereign foundation models. Public institutions must define responsibilities in data-processing workflows, conduct ex ante risk assessments, incorporate auditability requirements into public procurement, and establish procedural channels of appeal. The conceptual frameworks of UNESCO (2022) and the OECD (2021) converge on the view that ethical rules become effective only when linked to the operational duties of public institutions and the instruments of state policy. Mechanically transferring model ethics codes to jurisdictions with limited state capacity may produce a short-term display effect. Without an advanced implementation infrastructure, however, such measures will have little influence on how public power is exercised in practice.

The U.S. National Institute of Standards and Technology's Artificial Intelligence Risk Management Framework, NIST AI RMF 1.0, translates this institutional requirement into four cross-cutting functions: govern, map, measure, and manage (Tabassi, 2023). Performing these functions is not a one-time formal compliance check but a continuously recurring process throughout the system life cycle. Where public information assets have already been inventoried, regulatory powers assigned, monitoring processes developed, and incident records standardized, public authorities can manage emerging risks through established administrative processes. In the absence of this foundation, institutions must build bespoke controls for each system, rapidly increasing transaction costs and fragmenting the accumulation of institutional experience. The identified state-capacity gap therefore affects not only the speed with which regulatory documents can be produced but also the state's ability to sustain a continuous risk-management cycle.

CONCLUSION

The study shows that digital state capacity is a strong predictor of the institutionalization of AI governance.

The rank correlation of 0.733 between the 2022 GTMI score and the status of AI regulation in 2025, together with the sharp polarization across quartiles, confirms that regulatory governance frameworks for AI do not emerge in an institutional vacuum. When the state apparatus possesses stable capabilities in data management, digital public services, interagency coordination, and strategic transformation, the likelihood of an institutionalized legal regime is several times greater.

The findings do not, however, purport to establish a comprehensive causal model of technological diffusion. An observational design covering two periods cannot eliminate the effects of unobserved confounders such as macroeconomic prosperity, legal culture, regional learning, or foreign-policy commitments. Nor does the existence of a formal regulation guarantee adequate implementation. Future research should operationalize measures of how institutions actually function within executive government. These measures should include algorithmic impact-assessment procedures, the operation of independent audit boards, standards for human oversight, access to appeal bodies, and contractual requirements for information technology providers. Extended dynamic panels and micro-level analysis of unit data would allow the concrete causal pathways through which state capacity operates to be tested.

The principal policy recommendation is that readiness for AI applications should not be treated as an isolated sectoral technology program. Investment in national data governance, standardized interoperability, regulatory and legal alignment, workforce reskilling, and service design form the indispensable foundation for the institutionalization of AI. International technical assistance for capacity-constrained countries should strengthen core administrative functions rather than merely encourage the production of regulations on paper. Otherwise, the declining cost of applied AI tools will carry accumulated structural inequality into a new digital domain and entrench it rather than produce convergence in public-administration standards.

For implementation, a three-tier hierarchy for developing state capacity may be proposed:

Foundational level: establish reliable public records, assure data quality, protect critical information infrastructure, and implement basic interoperability protocols.

Intermediate level: formalize interagency coordination, adopt competitive and transparent rules for the public procurement of information technology solutions, define the limits of oversight authority, and develop specialist personnel.

Advanced level: establish AI-specific legal institutions, including algorithmic impact assessment, model auditing, procedural safeguards for explainability, the primacy of human intervention, and appeal mechanisms.

Attempting to impose the third tier before the first two are in place may generate a premature and largely symbolic body of regulation; in practice, it will lead to regulatory fragmentation and institutional irresponsibility. National road maps should therefore coordinate the adoption of final ethical standards with a binding timetable for the gradual strengthening of foundational institutional layers.

Public monitoring should likewise extend beyond a binary determination of whether a document exists. Quantifiable indicators should establish whether institutions maintain registers of high-risk algorithmic systems, how frequently risk assessments are updated, which audit provisions are included in supplier contracts, and the statutory processing time for citizen appeals against automated decisions. These measures should be complemented by assessments of public-sector reskilling programs, the independence of oversight bodies, and obligations to publish incident reports. Such an analytical profile would reveal the distance between formal declarations and actual administrative practice. In cross-national comparison, moving from a one-dimensional aggregate classification to a profile of component-level gaps would identify imbalances within national regulatory frameworks.

The architecture of international partnerships should reflect this differentiation. In advanced jurisdictions, priorities include harmonizing cross-border standards, conducting certified audits of neural networks, and validating risk-assessment systems. In administrations that lack foundational systems, the first priorities are to assign data responsibility clearly to individuals and units, digitize core records, establish secure data-exchange layers, and create an operational coordination body. Applying uniform policy packages to all states disregards fundamental differences in their starting positions. Donor technical programs should be differentiated by institutional maturity and should prioritize the long-term reproduction of institutional memory, local staff capacity, and stable budget financing over short-term consultancy interventions.

Finally, the findings indicate that the functional relationship between AI governance and digital state capacity is not unidirectional. Requirements to conduct algorithmic impact assessments or ensure data traceability may prompt comprehensive modernization of national administrative systems. Testing this feedback hypothesis lies beyond a two-wave research design, but the core policy requirement remains unchanged: reliable and socially responsible AI systems depend on governance capacities accumulated institutionally over many years. The effectiveness of ethics guidelines is determined by the coordinated and simultaneous development of legal rules, data infrastructure, bureaucratic capabilities, and a functioning system of public accountability.

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THE EFFECT OF DIGITAL PROGRESS ON INEQUALITY REDUCTION AND THE TRANSFORMATION OF DIGITAL STATE CAPACITY IN THE AGE OF ARTIFICIAL INTELLIGENCE

DİJİTAL İLERLEMENİN EŞİTSİZLİĞİ AZALTMA ETKİSİ VE YAPAY ZEKÂ ÇAĞINDA DİJİTAL DEVLET KAPASİTESİNİN DÖNÜŞÜMÜ

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ÖZET

Dijital teknolojilerin yaygınlaşması ve yapay zekâya dayalı düşük maliyetli uygulamaların ortaya çıkması, teknolojik açıdan geride kalan kamu yönetimlerinin zaman içinde gelişmiş dijital devletlerle aralarındaki farkı kapatabileceğine ilişkin tekno iyimser beklentileri güçlendirmektedir. Ancak dijital devlet kapasitesi ortak altyapı, temel kamu bilgi sistemleri, olgun elektronik hizmetler, insan sermayesi ve kurumsal tutarlılık üzerinde birikimli biçimde oluşuyorsa genel teknolojik ilerleme ülkeler arasındaki farklılıkların kendiliğinden eşitlenmesine yol açmayabilir. Bu çalışma, genel teknolojik ilerleme ile devlet kapasitesindeki yakınsamayı kavramsal olarak birbirinden ayırmakta ve 2022 ile 2025 dönemindeki dinamiklerini ampirik olarak değerlendirmektedir.

Analiz, Dünya Bankasının GovTech Olgunluk Endeksi'nin birbirini izleyen iki sürümünde eşleştirilen 197 ulusal ekonomiden oluşan dengeli bir panele dayanmaktadır. Küresel ortalama GTMI puanı 0,5534'ten 0,5891'e yükselmiş; ortalama 0,0357'lik artış istatistiksel olarak anlamlı bulunmuştur (%95 bootstrap güven aralığı [0,0227; 0,0496]). Bununla birlikte mutlak yayılım artmıştır: standart sapma 0,2621'den 0,2738'e yükselmiş, 90. ve 10. yüzdelikler arasındaki desil farkı P90 eksi P10 ise 0,6631'den 0,7331'e genişlemiştir ve artışa ilişkin güven aralığı sıfırı dışlamaktadır. Göreli eşitsizlik göstergeleri ters yönde hareket etmiştir: varyasyon katsayısı 0,4736'dan 0,4647'ye, Gini katsayısı ise 0,2707'den 0,2650'ye gerilemiştir. Aynı zamanda ülkeler arasındaki sıralama olağanüstü istikrarlı kalmıştır ve Spearman sıra korelasyonu $\rho = 0{,}925$'tir.

Bulgular, genel dijital ilerlemenin devlet kapasitesindeki yakınsamayla özdeş olmadığını göstermektedir. Ortalamalardaki artış, göreli eşitsizlikte sınırlı bir azalışla ve aynı anda dağılımın alt ve üst uçları arasındaki mutlak mesafenin genişlemesiyle birlikte gerçekleşebilir. Yapay zekâ çağında dijital farklılaşma, teknolojinin fiziksel erişilebilirliğinden çok kamu otoritelerinin yeni araçları idari düzenlemelere dâhil etme ve güvenilir yönetişim çerçeveleri oluşturma yönündeki kurumsal kapasiteleri üzerinden değerlendirilmelidir.

Anahtar kelimeler: Dijital devlet kapasitesi; dijital eşitsizlik; teknolojik yakınsama; yapay zekâ; karşılaştırmalı kamu yönetimi.

ABSTRACT

The diffusion of digital technologies and low-cost artificial intelligence applications has strengthened the expectation that technologically lagging public administrations can gradually catch up with more advanced digital states. Yet digital state capacity develops cumulatively through shared infrastructure, core government systems, online services, human resources, and institutional capabilities. General technological progress may therefore occur without automatically narrowing cross-country differences. This study distinguishes progress from capacity convergence and examines change between 2022 and 2025.

The analysis matches 197 economies across two editions of the World Bank GovTech Maturity Index. Mean GTMI increased from 0.5534 to 0.5891, a mean gain of 0.0357 (95% bootstrap confidence interval 0.0227-0.0496). Absolute dispersion nevertheless increased: the standard deviation rose from 0.2621 to 0.2738, while the gap between the 90th and 10th percentiles widened from 0.6631 to 0.7331; the confidence interval for the latter change excludes zero. Relative inequality measures move differently.

The coefficient of variation declined from 0.4736 to 0.4647 and the Gini coefficient from 0.2707 to 0.2650. Cross-country ranks remained highly persistent (Spearman ρ=0.925).
The findings show that digital progress is not equivalent to capacity convergence. Average improvement can coincide with a modest decline in relative inequality and a wider absolute distance between the lower and upper tails. In the age of AI, digital inequality should therefore be assessed not only as access to technology, but also as the ability of public institutions to embed new tools in service processes and governance arrangements.
Keywords: Digital state capacity; digital inequality; technological convergence; artificial intelligence; comparative public administration.

INTRODUCTION

The rapid development of cloud services, widely accessible open-source software, and generative artificial intelligence models is substantially lowering the cost and threshold of access to advanced technologies for public authorities. This trend has strengthened hopes that lagging jurisdictions can leapfrog the construction of extensive analog or early-stage digital infrastructure and move closer to global standards in digital government. Yet a considerable institutional distance separates the formal availability of a software tool from its conversion into a reliable and continuously operating public service. The World Bank's World Development Report, Digital Dividends, demonstrates that the diffusion of technology alone does not generate development returns; its ultimate effects depend on analog complements such as the regulatory environment, human capital, and institutional accountability (World Bank, 2016).

In the context of digital government, these institutional complements range from core population and legal-entity registers to secure protocols for interagency data exchange, and from citizen-centered public interfaces to effective feedback mechanisms. The digital-era governance paradigm developed by Dunleavy and colleagues advocates reintegrating fragmented public functions and restructuring the system around citizens' needs as a whole (Dunleavy et al., 2006). Mergel, Edelmann, and Haug (2019) define digital transformation as a comprehensive restructuring of organizational structures, administrative arrangements, and cross-sectoral relationships that extends far beyond the use of information technology. These studies converge on a common proposition: equal access to software does not guarantee a simultaneous increase in state capacity because every technology operates through established organizational processes and administrative capabilities.

The concept of public platform governance makes this dependence even more visible. Janssen and Estevez (2013) argue that shared services and modular components can optimize public expenditure, but require sophisticated interagency coordination, common standards, and end-to-end interoperability. The emergence of an inexpensive digital solution does not, in other words, automatically create an integrated government platform. If core components such as identification and authentication, government payment gateways, notification systems, and secure data exchange remain fragmented, each institution must recreate its own local solution. This structural constraint explains why falling market prices for information technology products do not reduce organizational gaps between states at the same rate.

Academic debate on convergence must clearly distinguish between two research questions:

Is the average level of states' digital capacity increasing?

Is differentiation among states, in other words dispersion, declining?

An affirmative answer to the first question does not logically require an affirmative answer to the second. If the digital front-runners continue to extend their advantage at a faster rate, scores may rise across the entire sample while the absolute distance between countries persists or even widens. The assessment of inequality also depends critically on the selected measure. Standard deviation and decile gaps capture the absolute scale of dispersion, whereas the coefficient of variation, the Gini coefficient, and the Theil index measure relative dispersion against a rising mean.

This distinction is especially important in the analysis of composite indices. The selection of underlying indicators, normalization methods, and weighting coefficients directly shapes the final distribution; a single inequality measure therefore cannot fully represent a multidimensional pattern (OECD et al., 2008).

Bannister and Connolly (2014) similarly warn against equating growth in the aggregate volume of electronic transactions with an automatic increase in public value. An aggregate digital maturity score is not equivalent to the actual quality or social inclusiveness of public services.

Using the World Bank's 2022 and 2025 GTMI data, this study addresses three research questions:

Has the average capacity of comparable national economies increased?

Have measures of absolute and relative inequality changed concurrently?

How stable have states' positions in the global distribution remained?

The central hypothesis is that although average indicators of digital maturity have risen globally, the absolute gap between economies at the upper and lower ends of the distribution has not tended to narrow. The study does not directly measure the effects of the AI era. The resulting structural distributions nevertheless provide a basis for evaluating the initial institutional conditions on which current disparities in AI capacity are developing.

DATA AND METHODS

Operationalization and Data Sources

The GovTech Maturity Index tracks public-sector digital transformation along four main dimensions: core government systems and shared digital infrastructure, the maturity of online public services, digital citizen engagement and CivicTech, and supporting institutional enablers consisting of strategy, legislation, innovation, and human capital. Index values range from 0 to 1, and economies are classified into four maturity groups, from leading Group A to lagging Group D (World Bank, 2022; Vasconcelos et al., 2025). The 2025 edition maintained continuity across 48 core indicators and introduced limited calibrations to incorporate three new parameters. The index's authors emphasize that the GTMI is a diagnostic tool for monitoring reform, not an official ranking of government effectiveness.

The 2022 dataset dated March 2023 was matched to the December 2025 database using international country codes (World Bank, 2023, 2025). Nicaragua, for which no numerical estimate was available for 2025, was removed from the initial sample of 198 economies, producing a balanced panel of 197 jurisdictions. Using the same composition of countries at both points in time eliminated the potential distortion of means caused by changes in sample structure. No missing-value imputation was performed. Overall progress was assessed through changes in the mean GTMI score and country-level trajectories. Absolute dispersion was measured with the standard deviation, the P90–P10 gap between the 90th and 10th percentiles, the interquartile range, and the full range of the distribution. Relative inequality was measured with the coefficient of variation, defined as the standard deviation divided by the mean, the Gini coefficient, and the Theil index. The reliability of changes between 2022 and 2025 was tested using 10,000 nonparametric paired bootstrap replications. The stability of country rankings was evaluated with Spearman's rank correlation. Finally, the relationship between the 2022 baseline and growth over the following three years was tested with a linear regression model using HC3 robust standard errors based on the Huber–White and MacKinnon–White specification.

Overall Progress

Across the 197 comparable economies, the mean GTMI score increased from 0.5534 in 2022 to 0.5891 in 2025. The mean net gain was 0.0357, with a paired 95% bootstrap confidence interval of [0.0227, 0.0496]. The median also rose, from 0.5743 to 0.6291. These results clearly indicate global progress in public-sector digital maturity, but the gains were distributed very unevenly.

Across the 2022 baseline maturity groups, the mean gains were 0.0335 in Group A, 0.0364 in Group B, 0.0318 in Group C, and 0.0465 in Group D. Although the lagging Group D recorded a slightly larger nominal gain in absolute terms, within-group dispersion was substantial. The linear regression estimate indicated that a one-standard-deviation increase in the baseline score was associated with a change of only −0.0061 in subsequent growth (HC3 standard error = 0.0065; p = 0.349; 95% confidence interval [−0.0189, 0.0067]). The model explained only 0.4% of the total variance in change. This result rejects the hypothesis of unconditional beta convergence. A low starting level alone does not guarantee faster modernization.

Comparative Analysis of Absolute and Relative Inequality

Table 1 Changes in Distributional and Inequality Measures of Digital State Capacity in 2022 and 2025

Indicator	2022	2025	Change Δ	Analytical interpretation
Mean	0.5534	0.5891	+0.0357	Increase in overall digital state capacity
Standard deviation	0.2621	0.2738	+0.0117	Increase in the absolute dispersion of the distribution
Coefficient of variation	0.4736	0.4647	−0.0089	Limited contraction in relative dispersion
Gini coefficient	0.2707	0.2650	−0.0058	Slight decline in relative inequality
Theil index	0.1259	0.1252	−0.0007	Stability in the entropy-based inequality measure
P90–P10 decile gap	0.6631	0.7331	+0.0701	Statistically significant divergence between the extremes
Interquartile range IQR	0.4745	0.4703	−0.0041	Little practical change in the central distribution
Full range	0.9723	0.9870	+0.0147	Increase in the distance between extreme values

The calculations reveal divergent trends. While the mean index level increased, the standard deviation rose by 0.0117; its bootstrap confidence interval [−0.0003, 0.0236] narrowly included zero. By contrast, the P90–P10 decile gap widened by a statistically significant 0.0701 (95% confidence interval [0.0079, 0.1129]). The threshold for the bottom 10% of lagging countries fell from 0.2021 to 0.1827, while the threshold for the top 10% of leading countries rose from 0.8652 to 0.9158. The technological extremes of the distribution therefore moved markedly farther apart.

Measures of relative inequality, by contrast, suggest modest convergence. Because the denominator, the mean, grew more rapidly, the ratio of the standard deviation to the mean declined; the Gini and Theil coefficients also fell slightly. The confidence intervals for these changes clearly included zero, however, precluding any claim of robust relative convergence. The central conceptual result is that an arithmetic decline in relative ratios does not imply a reduction in the actual distance measured in index points. Absolute capacity and capabilities are decisive for building state capacity. The widening gap between front-runners and laggards is therefore a priority concern for international development policy.

Interpretation also depends substantially on the dynamics of quartile boundaries. When the upper and lower quartiles were recalculated in each reference year, the gap between their means increased from 0.6570 to 0.6873. When country composition was held fixed according to the 2022 baseline quartile boundaries, by contrast, the gap between these cohorts fell from 0.6570 to 0.6370. There is no statistical contradiction: the two measures answer different substantive questions. The extremes of the global distribution moved farther apart, while some economies in initially lagging groups displayed faster internal growth and raised their cohort means.

Institutional Persistence of Capacity and Challenges in the Age of Artificial Intelligence

Spearman's rank correlation between the 2022 and 2025 scores was exceptionally high at 0.925 (95% bootstrap confidence interval [0.900, 0.942]). Despite local fluctuations in individual jurisdictions' scores, the overall macrostructure of the global hierarchy remained almost unchanged. This inertia indicates that digital state capacity is accumulated institutional capital rather than an operational resource allocated to short-term projects.

Shared government platforms, interoperability standards, skilled public personnel, and interagency arrangements accumulate over decades on the basis of prior investment. Vial's (2019) theory of digital transformation likewise shows that technological change produces socioeconomic outcomes only when deep structural and organizational barriers are overcome.

The rapidly declining cost of AI tools cannot by itself eliminate the cumulative nature of this capacity. Deploying a pretrained neural network or connecting to a prediction model through an application programming interface has become easier. By contrast, properly cleaning and labeling public datasets, establishing a sound regulatory and legal foundation, overseeing providers, and giving citizens procedurally adequate reasons for decisions require substantial governance effort. Cordella and Tempini's (2015) analysis of the relationship between technology and bureaucracy shows that formal rules are not merely obstacles; they also provide the supporting structure for public equality, coordination, and legal responsibility. Implementing AI algorithms in the public sector requires administrative capacity capable of adapting these foundational principles seamlessly to radically new computational processes.

The core dimensions of the OECD's (2020) approach to digital government—data-driven government, platform logic, and user-centeredness—should be treated as an integrated whole. Advanced economies deploy machine-learning algorithms on functioning national platforms and established chains of interagency electronic services. Low-capacity jurisdictions, by contrast, must digitize core records, establish basic interoperability, and implement an advanced AI-governance framework simultaneously. This heavy concurrent burden prevents the affordability of applied software from producing genuine institutional equality.

The persistence of state capacity cannot be reduced to the availability of servers and networks. The OECD's (2021) study of digital-government governance systems emphasizes the interaction among organizational models, institutional policy instruments, and national context. The powers of a central digital-transformation authority or chief digital officer, public-procurement regulations, the status of data-protection officers, and the capabilities of specialist public personnel form a complementary system of institutional balance. Once established, this infrastructure can readily absorb new generations of technology; in its absence, pilot projects are likely to dissipate in organizational dead ends. The strong persistence of national rankings confirms that digital maturity is rooted in foundational organizational architecture rather than temporary communication campaigns.

The global context also demonstrates that progress and deep inequality can coexist. While recording an overall rise in global indices, the United Nations E-Government Survey 2024 draws attention to the continuing systemic isolation of African countries, least developed countries, and small island developing states (UN DESA, 2024). Because the United Nations methodology differs from the GTMI, its calculations cannot be used for direct validation. The qualitative conclusion of the two independent institutions is nevertheless the same: global digital progress does not automatically remove the institutional and infrastructural barriers facing lagging regions.

The study has several methodological limitations. The GTMI synthesizes survey data and open sources; in the 2025 cycle, 158 governments supplied information through self-reporting. Administrations' capacity to provide high-quality responses is related to their actual human-resource capacity. Limited changes in indicator composition also constrain the absolute comparability of the scales. A three-year interval is insufficient to establish long-run convergence curves. Caution is also required when applying the Gini index to ordinal scores because GTMI values do not represent physical income flows.

CONCLUSION

Between 2022 and 2025, average digital public-administration capacity increased steadily worldwide. This fact is not sufficient, however, to conclude that the digital divide between states has been overcome. While relative indicators declined only marginally, the standard deviation increased and the absolute gap between the upper and lower deciles of the distribution widened markedly. The exceptionally high persistence of national positions, reflected in a rank correlation of 0.925, demonstrates structural inertia in the global distribution of digital capacity.

These findings yield a central conclusion: the international community should treat technological progress and institutional convergence as distinct policy objectives.

Rising global averages are a positive trend, but general progress will not create equal starting conditions in the age of AI unless lagging countries first meet their foundational needs in records infrastructure, skilled personnel, and interagency coordination. International donor programs should move away from an excessive emphasis on transferring software licenses. Shared government platforms, permanent in-house developer teams, long-term technical-support budgets, clearly defined oversight powers, and regular measurement of service effectiveness should be designed as a single integrated package.

Future research should use multiyear panel series to examine absolute and relative convergence and compare composite maturity scores with objective outcome indicators, including citizens' successful completion of digital transactions, interface accessibility, user satisfaction, and the operation of algorithmic oversight mechanisms. Such a research design would clarify the conditions under which technological leapfrogging becomes a reality. At present, the empirical evidence is not encouraging: digital states continue to improve, but progress alone does not automatically narrow the institutional gap between them.

Publishing global mean indicators alone is wholly inadequate for monitoring public policy. Standard deviations, percentile gaps, coefficients of variation, and transition matrices between groups should be reported alongside means and medians. Particular attention should be paid to the absolute position of the bottom decile, P10, which indicates whether the most vulnerable administrative systems share in global development gains. Parallel monitoring of cohorts whose composition is fixed at baseline would show clearly whether a particular lagging group accelerates its development over time. This dual perspective prevents polarization at the extremes of the distribution from being concealed behind a reassuring rise in the global mean.

International assistance instruments should be tailored flexibly to the maturity levels of the state apparatus:

In countries with weak foundational systems, the priority is to establish core infrastructure encompassing citizens' digital identity, secure population and property registers, integrated payment systems, and secure interbank and interagency data exchange.

In countries at an intermediate level of maturity, the focus should shift to seamless interagency service chains organized around life events, integrated user-experience standards, and field research on user needs.

In highly advanced digital states, priorities should include detailed algorithmic audit mechanisms, composite proactive services, and advanced sovereign data-governance protocols.

This sequencing is not a rigid, linear doctrine; national context may alter the order of the steps. Even so, it offers a more realistic basis for development than approaches that compel every country to purchase the same advanced information systems under a discourse of technological convergence.

A critical methodological risk in contemporary digitalization-support programs is substituting the number of implemented pilot projects for genuine institutional development. A pilot demonstration can quickly produce a visible effect. Yet if system data are not updated automatically, the personal legal liability of public officials remains unclear, and the national budget contains no resources for operation and modernization, the project can never reach the scale of a sustainable state institution. Financing assessments should be based on total cost of ownership across the system's life cycle, including personnel, cybersecurity, data validation, and regular external audits. Common open standards can reduce duplicative expenditure, but their implementation depends less on programmers' technical expertise than on political commitment to transparent interagency agreement and public accountability.

Finally, the research agenda should prioritize the construction of harmonized long-term panel databases. Multilevel models that disaggregate overall progress into GTMI components should examine the effects of regional characteristics, national prosperity, and traditions of administrative law. Qualitative comparative case studies of countries with similar starting positions but diametrically opposed recent trajectories could reveal the roles of budget processes, reform leadership, public-procurement rules, and personnel policy. Addressing the central problems of the AI era requires rigorous statistical analysis of distributions to be combined with micro-level analysis of institutional mechanisms.

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TUZ KONSANTRASYONUNUN (10 G/L) CHLORELLA SOROKİNİANA KÜLTÜRLERİNDE PROTOZOON KONTAMİNASYONU VE BÜYÜMEYE ETKİSİ

EFFECT OF SALT CONCENTRATION (10 G/L) ON PROTOZOAN CONTAMINATION AND GROWTH IN CHLORELLA SOROKINIANA CULTURE

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ÖZET

Mikroalg kültürü, fotosentetik kapasiteye sahip mikroskobik, tek hücreli su yosunlarının kontrollü koşullar altında çoğaltılması sürecidir. Bu biyoteknolojik uygulama; gıda, kozmetik, hayvancılık yem katkısı ve biyoyakıt üretimi gibi farklı endüstriyel alanlarda kullanılmak üzere gerçekleştirilir. Kültürleme işlemleri, genellikle açık sistemler (açık havuzlar) veya çevresel parametrelerin daha hassas biçimde kontrol edilebildiği kapalı sistemler (fotobiyoreaktörler) aracılığıyla yürütülmektedir.

Mikroalg kültürlerinde verimi düşüren veya tüm sistemi çökerten kültür patlaması/çöküşü olarak adlandırılan başlıca biyolojik etkenlerden olan kültürle beslenen protozoon zooplankton türleridir. Açık havuzlarda veya kapalı sistemlerde bu kontaminasyonlar büyük ekonomik kayıplara yol açar.

Bu amaçla, *Chlorella sorokiniana* mikroalginin 10 g/L okyanus tuzu içeren diğeri ise tuz içermeyen kontrol ortamı olmak üzere iki farklı kültür koşulu oluşturulmuş ve mikroalgin büyüme performansı ile mikrobiyal yükleri düzenli aralıklarla değerlendirilmiştir. Deneysel süreçte, kültürlerin gelişim seyri günlük gözlemlerle takip edilmiş, biyokütle miktarı spektrofotometrik ölçümle belirlenmiş ve kontaminasyon düzeyleri ise mikroskop altında görsel olarak incelenmiştir. Elde edilen bulgular, tuz içermeyen ortamda protozoon kontaminasyonun daha hızlı ve yoğun şekilde geliştiğini, bunun da kültürlerin stabilitesini olumsuz etkilediğini göstermiştir. Buna karşılık, 10 g/L okyanus tuzu içeren ortamda protozoon gelişiminin belirgin biçimde baskılandığı, kültürlerin daha uzun süre stabil kaldığı ve biyokütle kaybının daha düşük olduğu saptanmıştır. Bu durum, tuz konsantrasyonunun mikroalg kültürlerinde doğal bir biyolojik bariyer görevi gördüğünü ve protozoonların çoğalmasını sınırlayarak kültür güvenliğini artırdığını ortaya koymaktadır.

Sonuç olarak, bu çalışma *Chlorella sorokiniana* üretiminde 10 g/L tuzluluk koşulunun büyüme performansı açısından ve aynı zamanda kontaminasyon kontrolü bakımından da kritik öneme sahip olduğunu vurgulamaktadır. Mikroalg biyoteknolojisinde, özellikle endüstriyel ölçekli üretimlerde, tuz konsantrasyonunun doğru ayarlanması kültürlerin sürdürülebilirliği ve güvenliği için stratejik bir yaklaşım olarak değerlendirilmektedir.

Anahtar kelimeler: *Chlorella sorokiniana*, Mikroalg, Protozoon, Okyanus tuzu.

ABSTRACT

Microalgae culture is the process of growing microscopic, single-celled algae with photosynthetic capacity under controlled conditions. This biotechnological application is used in various industrial fields, including food, cosmetics, livestock feed additives, and biofuel production. Cultivation processes are generally carried out in open systems (open ponds) or in closed systems (photobioreactors), where environmental parameters can be controlled more precisely.

They are culture-feeding protozoan zooplankton species that are among the main biological factors causing culture explosion or collapse, which reduce the efficiency of microalgae cultures or can even cause the entire system to fail. In both open ponds and closed systems, these contaminations cause significant economic losses.

To investigate this, two culture conditions were established for the microalga *Chlorella sorokiniana*: one containing 10 g/L ocean salt and the other a salt-free control medium. The growth performance and microbial load of the microalga were evaluated at regular intervals. During the experiment, the growth of the cultures was monitored through daily observations, the biomass was measured spectrophotometrically, and contamination levels were examined microscopically. The findings showed that protozoan contamination developed more rapidly and intensely in a salt-free environment, adversely affecting culture stability. In contrast, protozoan growth was significantly suppressed, cultures remained stable for longer periods, and biomass loss was lower in a medium containing 10 g/L ocean salt. This shows that salt concentration acts as a natural biological barrier in microalgal cultures, improving culture safety by limiting protozoan growth.
In conclusion, this study demonstrates that a salinity of 10 g/L is critical for both growth performance and contamination control in *Chlorella sorokiniana* production. In microalgae biotechnology, particularly in industrial-scale production, precise adjustment of salt concentration is considered a strategic approach to ensure the sustainability and safety of cultures.
Keywords: *Chlorella sorokiniana*, Microalgae, Protozoon, Ocean salt.

GİRİŞ

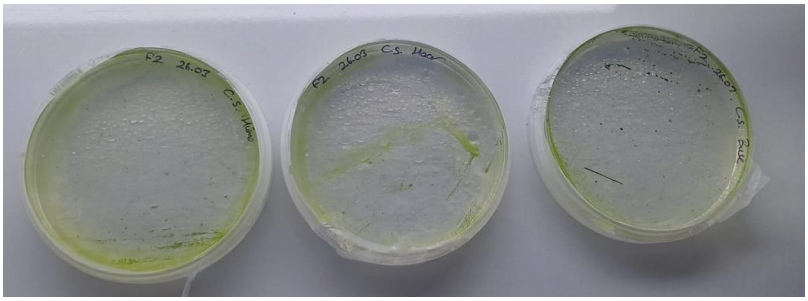
Mikroalgler, son yıllarda biyoteknoloji, akuakültür ve çevre mühendisliği alanlarında stratejik öneme sahip biyolojik kaynaklar olarak öne çıkmaktadır (Han, Lu, Fan ve Zhou, 2019; Grama, Liu, Li, 2022). Yüksek protein içeriği, değerli pigmentler (klorofil, karotenoidler, fikobiliproteinler) ve biyoyakıt üretim potansiyeli sayesinde mikroalgler, hem gıda ve yem endüstrisinde hem de farmasötik ve enerji sektörlerinde kullanılmaktadır (Khan, Shin ve Kim, 2018; Rahman, 2020). Bununla birlikte, mikroalg kültürlerinin sürdürülebilir üretiminde karşılaşılan en büyük sorunlardan biri kontaminasyondur (Wang, Zhang, Chen, Wang ve Liu, 2013; Molina vd., 2019). Özellikle protozoonlar, mikroalg kültürlerinde hızlı çoğalma yetenekleriyle biyokütle kaybına, kültürün çökmesine ve üretim verimliliğinin ciddi şekilde azalmasına yol açmaktadır (Day, Gong ve Hu, 2017). Endüstriyel ölçekli üretimlerde bu tür kontaminasyon riskleri, ekonomik kayıpların yanı sıra üretim sürekliliğini de tehdit etmektedir.
Kontaminasyonun önlenmesine yönelik çeşitli stratejiler geliştirilmiştir. Fiziksel yöntemler (filtrasyon, UV ışınlama), kimyasal uygulamalar (antimikrobiyal ajanlar, dezenfektanlar) ve biyolojik yaklaşımlar (rekabetçi türlerin kullanımı) bu kapsamda değerlendirilmektedir (Gallardo-Rodríguez, Astuya-Villalón, Llanos-Rivera, Avello-Fontalba ve Ulloa-Jofré, 2019). Ancak bu yöntemlerin çoğu, mikroalglerin büyüme performansını olumsuz etkileyebilmekte veya üretim maliyetlerini artırabilmektedir. Bu nedenle, kültür ortamının tuzluluk düzeyi gibi doğal parametrelerin kullanımı, hem ekonomik hem de biyolojik açıdan daha uygulanabilir bir çözüm olarak dikkat çekmektedir. Tuz konsantrasyonu, mikroalglerin ozmotik dengesi ve metabolik aktiviteleri üzerinde doğrudan etkili olmakla birlikte, protozoonların gelişimini baskılayıcı bir faktör olarak da rol oynayabilmektedir.
Tatlı su mikroalg türlerinden biri olan *Chlorella sorokiniana*, yüksek büyüme hızı, besin açısından zengin biyokütle üretimi ve geniş adaptasyon kapasitesi nedeniyle araştırmalarda sıkça tercih edilmektedir. Bununla birlikte, bu türün farklı tuzluluk koşullarına verdiği yanıtların ve kontaminasyon riskine karşı gösterdiği toleransın ayrıntılı olarak incelenmesi, kültür güvenliği açısından kritik öneme sahiptir. Özellikle 10 g/L tuz konsantrasyonu, hem mikroalg büyümesini sürdürülebilir kılabilecek hem de protozoon kontaminasyonunu sınırlayabilecek bir eşik değer olarak öne çıkmaktadır.
Bu çalışmada, 10 g/L tuz konsantrasyonunun *Chlorella sorokiniana* kültürlerinde protozoon kontaminasyonu ve büyüme performansı üzerindeki etkileri sistematik olarak değerlendirilmiştir. Araştırmanın amacı, mikroalg üretiminde tuzluluk koşullarının hem biyokütle verimliliği hem de kültür stabilitesi açısından stratejik bir parametre olarak kullanılabilirliğini ortaya koymaktır. Elde edilen bulgular, endüstriyel mikroalg üretiminde kontaminasyon kontrolüne yönelik yeni yaklaşımların geliştirilmesine katkı sağlayacaktır.

ARAŞTIRMA ve BULGULAR

Chlorella sorokiniana Mikroalg Türü ve Kültür Koşulları

Bu çalışmada tatlı su mikroalg türlerinden *Chlorella sorokiniana* kullanılmıştır. Saf kültür, laboratuvar koşullarında steril tekniklerle çoğaltılmış (Şekil 1) ve deneysel uygulamalarda kullanılmıştır. Kültürler, 4000 mL hacimli plastik şişelerinde, sürekli havalandırma ve ışık altında yetiştirilmiştir.

Besiyeri olarak F/2 ortamı temel alınmış (Tablo 1), gerekli makro ve mikro besin elementleri eklenmiştir (Conde vd., 2025). Kültür sıcaklığı 27±2 ℃ de tutulmuştur.



Şekil 1. Chlorella sorokiniana Saf Kültür Üretimi

Tablo 1. F/2 Ortamı

Kimyasallar	Stok Solüsyon	Kültür Ortamına İlave Edilen Miktarı
$NaNO_3$	75 g	1 mL
$NaH_2PO_4H_2O$	5,65 g	1mL
İz element solüsyonu		1 mL
Vitamin Solüsyonu		1 mL

Kimyasallar	İz Element Stok Solüsyon g/L
Na_2EDTA	4,16
$FeCl_3.6H_2O$	3,15
$CuSO_4.6H_2O$	0,01
$ZnSO_4.6H_2O$	0,022
$CoCl_2.6H_2O$	0,01
$MnCl_2.6H_2O$	0,18
$Na_2MoO_4.6H_2O$	0,006

Kimyasallar	Vitamin Stok Solüsyon g/L
Siyanokobalamin (Vit. B_{12})	0,0005
Thiamin (Vit. B_1)	0,1
Biotin	0,0005

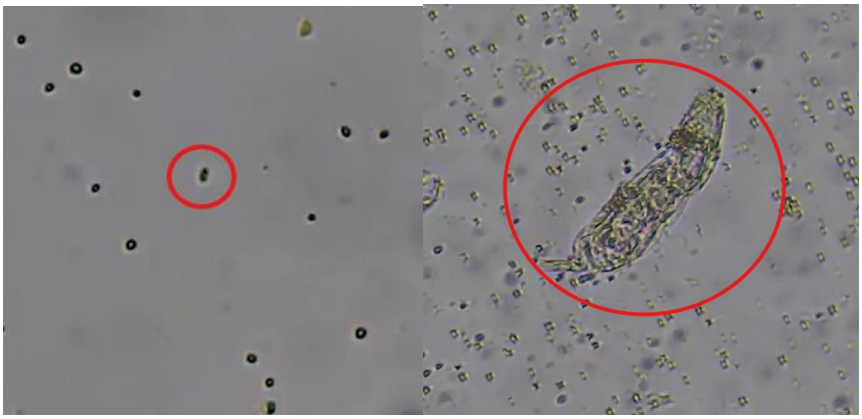
***Chlorella sorokiniana* Tuzlu ve Tuzsuz Ortamın Optik Büyümesi**

Kültürlerin büyümesi, 750 nm dalga boyunda spektrofotometrik ölçümlerle günlük olarak takip edilmiştir.



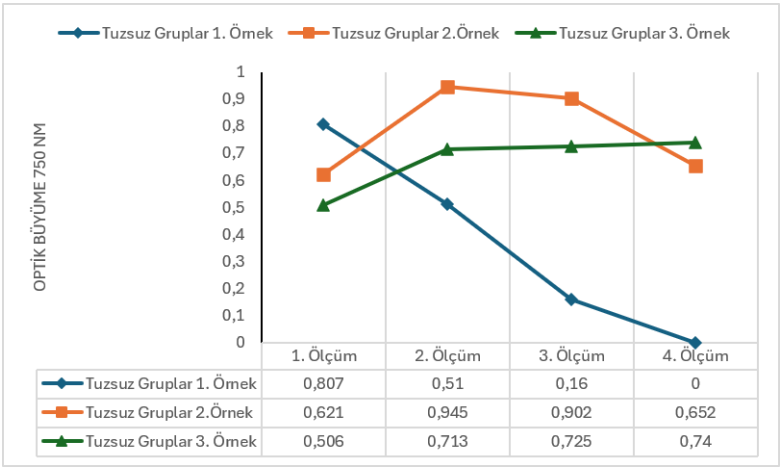
Şekil 2. Chlorella sorokiniana Tuzlu Ortamın Optik Büyümesi

Şekil 2, tatlı su mikroalgi *Chlorella sorokiniana*'nın 10 g/L okyanus tuzu içeren ortamda gösterdiği günlük hücre çoğalmasının miktarını temsil etmektedir. Kültürlerin büyümesi gün aşırı olarak 750 nm dalga boyunda spektrofotometrik ölçümlerle izlenmiştir.
10 g/L okyanus tuzu içeren bu ortamda, mikroalgi avlayarak sistemin çöküşüne yol açan protozoonların gelişimi belirgin biçimde baskılanmıştır (Şekil 3). Protozoonların çoğalmasının engellenmesi sayesinde, Şekil 2'de temsil edilen tuzlu ortamdaki kültürler çok daha uzun süre stabil kalmış ve biyokütle kaybı son derece düşük seviyelerde tutulmuştur.



Şekil 3. Tuzlu ve Tuzsuz Ortamın Protozoan Bakımından Görsel Değerlendirmesi

Grafikte gözlenen kararlı optik büyüme seyri, 10 g/L okyanus tuzu konsantrasyonunun mikroalg kültüründe doğal bir biyolojik bariyer görevi üstlendiğini doğrulamaktadır. Bu tuzluluk seviyesi, mikroalgin gelişimine ölümcül bir zarar vermezken kontaminasyon riskini başarıyla yönetmektedir.



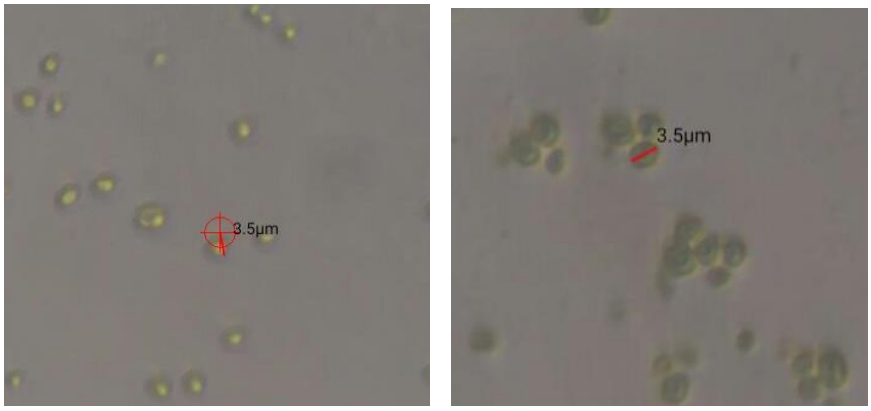
	1. Ölçüm	2. Ölçüm	3. Ölçüm	4. Ölçüm
Tuzsuz Gruplar 1. Örnek	0,807	0,51	0,16	0
Tuzsuz Gruplar 2.Örnek	0,621	0,945	0,902	0,652
Tuzsuz Gruplar 3. Örnek	0,506	0,713	0,725	0,74

Şekil 4. Chlorella sorokiniana Tuzsuz Ortamın Optik Büyümesi

Şekil 4, herhangi bir tuz ilavesi yapılmayan kontrol ortamındaki mikroalg gelişiminin günlük seyrini 750 nm dalga boyunda spektrofotometrik ölçümlerle göstermektedir.
Tuzsuz kontrol ortamında, mikroalglerle beslenen protozoon kontaminasyonu çok daha hızlı ve yoğun bir şekilde gelişmiştir. Tatlı su ortamı, bu avcı zooplanktonların çoğalması için ideal bir zemin hazırlamıştır.
Koruyucu bir engelin bulunmadığı bu ortamda, protozoonların hızlı artışı kültürlerin stabilitesini doğrudan olumsuz etkilemiştir. Spektrofotometrik ölçümlerde (optik büyümede) gözlenen dengesizlikler ve olası düşüşler, protozoonların mikroalgleri tüketmesiyle tetiklenen hızlı bir biyokütle kaybına ve kültür çöküşüne işaret etmektedir.

Chlorella sorokiniana Tuzlu ve Tuzsuz Ortamın Hücre Boyutu

Mikroskobik görüntüler trinoküler mikroskop (Soptop CX40) yardımıyla dijital analiz ile hücre çapı ölçülmüş, ortalama değerler hesaplanmıştır (Şekil 5).



Şekil 5. Chlorella sorokiniana Hücrelerin Görseli

Tablo 2. Chlorella sorokiniana Hücre Boyutu

Tuzlu ortam (10 g/L)	Tuzsuz ortam
3,950±0,339 µm	3,916±0,466 µm

Veriler ortalama ± standart sapma (SD) olarak sunulmuştur.

Tablo 2, *Chlorella sorokiniana* mikroalginin 10 g/L okyanus tuzu içeren ortam ile tuzsuz (kontrol) ortamdaki hücre boyutlarını (hücre çapını, µm) karşılaştırmalı olarak sunmaktadır.

- Tuzlu Ortam (10 g/L): Hücre boyutu ortalama 3,950 ± 0,339 µm olarak ölçülmüştür.
- Tuzsuz Ortam (Kontrol): Hücre boyutu ortalama 3,916 ± 0,466 µm olarak ölçülmüştür.

İki grup arasındaki ortalama hücre çapı farkı son derece küçüktür (yalnızca ~0,034 µm). Bu durum, 10 g/L seviyesindeki okyanus tuzu konsantrasyonunun mikroalg üzerinde yıpratıcı bir ozmotik strese yol açmadığını gösterir. Hücreler, tuz varlığında aşırı büzülme veya kontrolsüz şişme göstermeden morfolojik yapılarını ve normal boyutlarını başarıyla korumuştur.

Tuzlu ortamda elde edilen standart sapma değerinin (±0,339 µm), tuzsuz ortama (±0,466 µm) kıyasla daha düşük olması dikkat çekicidir. Bu durum, tuzlu ortamdaki hücrelerin boyutsal olarak daha homojen bir dağılım sergilediğine işaret eder. Tuzsuz ortamda protozoon kontaminasyonunun çok daha hızlı ve yoğun gelişmesi, alg popülasyonu üzerinde fizyolojik dengesizlik yaratarak hücre boyutlarındaki değişkenliği (standart sapmayı) artırmış olabilir.

Tablo 2'deki morfolojik kararlılık verileri, 10 g/L tuzluluk oranının alg sağlığına ve hücresel bütünlüğüne zarar vermediğini kanıtlar. Bu durum, söz konusu konsantrasyonun kültür gelişimini sekteye uğratmadan avcı protozoonları baskılayan son derece güvenli bir biyolojik koruma bariyeri olarak kullanılabileceğini doğrulamaktadır.

Jeva vd. (2025) tarafından yapılan araştırma da *C. sorokiniana* için en ideal tuzluluk konsantrasyonunun 10 g/L olduğunu doğrulamaktadır. Bu seviyede mikroalg hücre yoğunluğu kontrol grubuna kıyasla 1,27 kat artış göstermiş ve spesifik büyüme hızı (SGR) en yüksek düzeye ulaşmıştır.

Diğer kaynaklar (örneğin El-Adl vd., 2024 ve Jeva vd., 2025), tuzluluk oranı 20 g/L ve üzerine çıktığında hücre boyutunun ozmotik basınç nedeniyle aşırı büyüdüğünü (hücre devleşmesi), hücre bölünmesinin yavaşladığını ve klorofil/pigment sentezinin ciddi şekilde baskılandığını ortaya koymuştur.

Tüm bu veriler bir araya getirildiğinde, mikroalg biyoteknolojisinde 10 g/L okyanus tuzu uygulamasının;

1. Mikroalgin yapısal ve hücresel sağlığını bozmadan büyüme performansını artırdığı,
2. Azot dengesini bozmadan ve ek kimyasal maliyeti yaratmadan avcı zooplankton kontaminasyonunu engelleyen ekolojik, ucuz ve güvenli bir doğal biyolojik bariyer oluşturduğu kanıtlanmaktadır.

SONUÇ

Çalışmanın en temel sonucu, 10 g/L okyanus tuzu uygulamasının tatlı su mikroalgi *Chlorella sorokiniana* kültürlerinde avcı protozoonlara karşı doğal bir biyolojik bariyer görevi üstlendiğinin kanıtlanmasıdır. Tuzsuz kontrol ortamında protozoon kontaminasyonu son derece hızlı ve yoğun bir şekilde gelişerek kültür stabilitesini bozarken, 10 g/L tuz içeren ortamda protozoon gelişimi belirgin şekilde baskılanmış, kültürün daha uzun süre kararlı kalması sağlanmış ve biyokütle kayıpları asgari düzeye indirilmiştir.

1. Alg Gelişimi ve Hücresel Bütünlük (Ozmotik Tolerans)

Araştırma, 10 g/L tuz konsantrasyonunun *C. sorokiniana*'nın büyüme performansı ve hücresel sağlığı üzerinde yıpratıcı veya engelleyici bir etki yaratmadığını doğrulamaktadır. Dosyadaki Tablo 2 hücre boyutu verileri incelendiğinde; tuzlu ortamdaki ortalama hücre çapı (3,950±0,339 µm), tuzsuz ortamdaki hücre çapına (3,916±0,466 µm) son derece yakındır. Bu durum, mikroalgin bu tuzluluk seviyesinde aşırı büzülme veya şişme gibi ozmotik deformasyonlara uğramadan morfolojik bütünlüğünü ve sağlığını başarıyla koruduğunu gösterir.

2. Endüstriyel Sürdürülebilirlik İçin Stratejik Yaklaşım

Açık havuzlar (açık sistemler) veya kapalı fotobiyoreaktörlerde yaşanan protozoon istilaları, mikroalg üretim verimini düşüren ve tüm sistemi çökertebilen en büyük biyolojik tehdittir. Çalışmanın nihai değerlendirmesinde, tuz konsantrasyonunun 10 g/L seviyesinde doğru ayarlanmasının, endüstriyel ölçekli üretimlerde ek kimyasal maliyeti yaratmayan, sürdürülebilir ve güvenli bir kontaminasyon kontrol stratejisi olduğu vurgulanmaktadır.

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ZEBRA BALIĞI (DANİO RERİO) EMBRİYOLARINDA FARKLI İNKÜBASYON ORTAMLARININ MORFOLOJİK ETKİLERİNİN KARŞILAŞTIRILMASI

COMPARISON OF MORPHOLOGICAL EFFECTS OF DIFFERENT INCUBATION ENVIRONMENTS ON ZEBRAFISH (DANIO RERIO) EMBRYOS

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ÖZET

Zebra balığı (*Danio rerio*), genetik yakınlığı, şeffaf embriyoları ve hızlı üreme kapasitesi sayesinde günümüzde en yaygın kullanılan sucul model organizmalardan biridir. Bu özellikleri nedeniyle gelişim biyolojisi ve toksikoloji çalışmalarında tercih edilen önemli bir deney hayvanı olarak öne çıkmaktadır. Zebra balığı embriyolarının sağlıklı gelişimi için kullanılan E3 ortamı, izotonik bir tuz çözeltisi olup sodyum, potasyum, kalsiyum ve magnezyum gibi temel iyonları içerir. Bu ortam, osmotik ve pH dengesini koruyarak embriyo gelişimi için temiz, tekrarlanabilir ve güvenilir koşullar sağlamaktadır.

Bu çalışmada, farklı kimyasal içeriklere sahip üç yumurta ortamının (60x E3, 50x E3 ve 0.03 g/L okyanus tuzu çözeltisi) zebra balığı embriyolarının temel morfolojik özellikleri üzerindeki etkileri karşılaştırmalı olarak değerlendirilmiştir. Sağlıklı anaç bireylerden elde edilen embriyolar, üç farklı ortam grubuna ayrılarak inkübe edilmiş ve gelişimsel süreçler 24, 48, 72 ve 96. saatlerde stereo mikroskop altında incelenmiştir. Hayatta kalma oranı, koryondan çıkış (hatching) oranı ve yumurta çapı gibi parametreler sistematik olarak kaydedilmiştir. Elde edilen bulgular, inkübasyon ortamının iyonik dengesi ve ozmolaritesinin embriyo gelişimi için kritik öneme sahip olduğunu göstermektedir. Özellikle hazırlanması daha pratik olan 0.03 g/L okyanus tuzu çözeltisinin, sıklıkla kullanılan diğer ortamlara kıyasla embriyo gelişiminde anlamlı bir farklılık yaratmadığı belirlenmiştir. Sonuç olarak, bu çalışma zebra balığı embriyoları ile yürütülecek ileri araştırmalarda en uygun ve en pratik şekilde hazırlanabilecek inkübasyon ortamının seçimine katkı sağlamakta ve deneysel standartların geliştirilmesine yönelik önemli bir referans oluşturmaktadır.

Anahtar kelimeler: Embriyo, İnkübasyon, Okyanus tuzu, Zebra balığı.

ABSTRACT

The zebrafish (*Danio rerio*) is one of the most widely used aquatic model organisms today, thanks to its genetic similarity to humans, transparent embryos, and rapid reproductive capacity. Because of these characteristics, it stands out as an important experimental animal, preferred for studies in developmental biology and toxicology.

The E3 medium used for the healthy development of zebrafish embryos is an isotonic salt solution that contains essential ions such as sodium, potassium, calcium, and magnesium. This environment provides clean, consistent, and reliable conditions for embryo development by maintaining osmotic and pH balance.

In this study, the effects of three egg media with different chemical compositions (60× E3, 50× E3, and a 0.03 g/L ocean salt solution) on the basic morphological characteristics of zebrafish embryos were compared. Embryos obtained from healthy parent plants were separated into three different media groups, incubated, and their development was examined under a stereomicroscope at 24, 48, 72, and 96 hours. Parameters such as survival rate, hatching rate and egg diameter were systematically measured. The findings indicate that the ionic balance and osmolarity of the incubation medium are crucial for embryo development.

It was determined that the 0.03 g/L ocean salt solution, which is more practical to prepare, did not significantly affect embryo development compared with other commonly used media. In conclusion, this study supports the selection of the most suitable and practical incubation medium for further research with zebrafish embryos and serves as an important reference for the development of experimental standards.
Keywords: Embryo, İncubation, Ocean salt, Zebrafish.

GİRİŞ

Zebra balığı (*Danio rerio*), Asya' nın güney kısmı kökenli küçük yapılı bir tatlısu balığıdır ve son 30 yılda omurgalı genetiği, gelişim biyolojisi, toksikoloji ve biyomedikal araştırmalar için en önemli model organizmalardan biri haline gelmiştir (Spence, Gerlach, Lawrence ve Smith, 2008; Meyers, 2018; Ferrandino, 2024). İlk olarak 1822'de Francis Hamilton tarafından Ganges Nehri'nde tanımlanan bu tür, şeffaf embriyoları, hızlı gelişimi ve insana yüksek genetik benzerliği sayesinde bilimde öne çıkmaktadır (Ferrandino, 2024; Lima vd., 2025).

Ergin bireyler genellikle 3-5 cm boya ulaşmakta ve vücutlarının lateral yüzeyleri boyunca uzanan karakteristik mavi-siyah yatay çizgilerle tanınmaktadır (Schilling, 2002). Laboratuvar koşullarına kolay uyum sağlamaları, kısa yaşam döngüleri, düşük bakım maliyetleri ve yüksek üreme performansları zebra balığını araştırmalarda tercih edilen bir tür haline getirmektedir (Ribas ve Piferrer, 2014; Simonetti, Marques, Streit ve Oberst, 2015). Uygun çevresel koşullar altında dişi bir birey tek yumurtlamada yüzlerce yumurta bırakabilmekte ve dış döllenme yoluyla elde edilen embriyolar kısa sürede gelişim göstermektedir (Spence, Gerlach, Lawrence ve Smith, 2008).

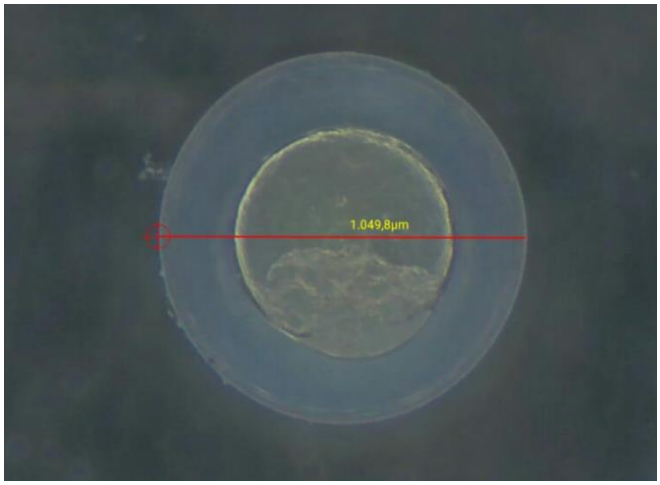
Farklı inkübasyon ortamlarının kullanılması zebra balığı embriyoları üzerindeki en kritik etkileri, ortamın iyonik dengesi ve ozmolaritesi (ozmotik basınç dengesi) ile doğrudan ilişkilidir. Bu iki unsur, embriyonun sağlıklı bir şekilde gelişebilmesi için ihtiyaç duyduğu osmotik ve pH dengesini koruyarak temiz ve güvenilir koşullar sağlamaktadır.

İnkübasyon ortamlarının embriyo gelişimi üzerindeki etkilerini belirlemede kullanılan ve kritik önem taşıyan morfolojik parametreler şunlardır:

- **Hayatta kalma oranı:** Embriyoların farklı ortamlardaki yaşamsal sürekliliğini gösterir.
- **Koryondan çıkış oranı:** Gelişimsel sürecin başarısını ve embriyonun yumurta kılıfından sağlıklı bir şekilde çıkıp çıkamadığını ortaya koyar.
- **Yumurta çapı:** Embriyonun fiziksel gelişimini ve morfolojik özelliklerini izlemek için sistematik olarak kaydedilir.
- **Larva uzunluğu:** Zebra balığı embriyolarının 96 hpf sonra yumurtadan çıkan larvaların morfolojik gelişimini izlemek amacıyla sistematik olarak kaydedilen parametredir.

Zebra balığı embriyolarının sağlıklı bir şekilde gelişimini sürdürebilmesi için laboratuvar ortamında kullanılan E3 ortamı, sodyum, potasyum, kalsiyum ve magnezyum gibi temel iyonları içeren izotonik bir tuz çözeltisidir. Bu ortam, osmotik ve pH dengesini hassas bir şekilde koruyarak embriyo gelişimi için temiz, tekrarlanabilir ve güvenilir koşullar sağlamaktadır. Laboratuvar çalışmalarında hem standartları korumak hem de uygulamaları kolaylaştırmak amacıyla, bu klasik ortamlara alternatif olabilecek pratik çözümlerin araştırılması büyük önem taşımaktadır.

Bu çalışma, farklı kimyasal içeriklere sahip üç farklı yumurta ortamının (60x E3, 50x E3 ve 0.03 g/L okyanus tuzu çözeltisi) zebra balığı embriyolarının temel morfolojik özellikleri üzerindeki etkilerini karşılaştırmalı olarak değerlendirmek amacıyla gerçekleştirilmiştir. Araştırma kapsamında, sağlıklı anaç bireylerden toplanan embriyolar üç farklı ortam grubuna ayrılmış ve gelişim süreçleri 24, 48, 72 ve 96. saatlerde stereo mikroskop altında incelenmiştir. Çalışma her bir grup için 8 kuyucuk ve her kuyucuk da iki embriyo olacak şekilde toplam 48 adet sağlıklı xebra balığı embriyosundan oluşmuştur (Şekil 1). Gelişimin seyrini belirlemek amacıyla embriyoların hayatta kalma oranı, koryondan çıkış (hatching) oranı ve yumurta çapı parametreleri sistematik olarak kaydedilerek ortamların morfolojik etkileri mercek altına alınmıştır.



Şekil 1. Zebra balığı Embriyo Görseli (%50 epiboli evresi <6 hpf)

Bu çalışma, OECD Test Kılavuzu 236 (Fish Embryo Acute Toxicity Test) esas alınarak yürütülmüştür. Deneysel prosedürlerde yalnızca 96 hpf'ye kadar olan zebrafish (Danio rerio) embriyoları kullanılmış ve tüm uygulamalar 120 hpf öncesinde tamamlanmıştır. Avrupa Birliği'nin hayvan deneylerine ilişkin 2010/63/EU Direktifi uyarınca, 120 hpf öncesindeki balık embriyoları korunan deney hayvanı olarak kabul edilmediğinden, bu çalışma için etik kurul onayı gerekmemektedir (Imath, Ragavendran, Kamaraj ve Raja, 2025; Ghodake vd., 2026).
Zebra balığı (*Danio rerio*) embriyolarının sağlıklı morfolojik gelişimi için hazırlanan farklı inkübasyon ortamlarının iyonik dengesi ve ozmolaritesi (ozmotik basınç dengesi) kritik bir öneme sahiptir. Bu çalışmada, klasik izotonik E3 laboratuvar ortamları (60x E3 ve 50x E3) ile pratik ve ekonomik bir alternatif olarak seçilen 0.03 g/L okyanus tuzu (ReeFlowers Caledonia Sea Salt®) çözeltisinin kimyasal formülasyonları, fizikokimyasal özellikleri ve bu ortamların embriyo morfolojisi üzerindeki etkileri karşılaştırmalı olarak incelenmiştir.

ARAŞTIRMA ve BULGULAR

Yumurta Gelişim Ortamlarının Fizikokimyasal Parametreleri

Zebra balığı (*Danio rerio*) embriyolarının sağlıklı morfolojik gelişimi için hazırlanan farklı inkübasyon ortamlarının iyonik dengesi ve ozmolaritesi kritik bir öneme sahiptir. Bu doğrultuda, çalışmada kullanılan klasik izotonik 60x E3 ve 50x E3 standart laboratuvar ortamları ile pratik bir alternatif olarak seçilen 0.03 g/L okyanus tuzu çözeltisinin kimyasal formülasyonları ve ölçülen fizikokimyasal özellikleri (iletkenlik, tuzluluk, TDS) Tablo 1'de ayrıntılı olarak karşılaştırılmıştır.

Tablo 1. Hazırlanan Yumurta Gelişim Ortamları

E3 ortamı 60X (Terzi, Lao ve Jacobo, 2024)	E3 ortamı 50X (Rho, vd., 2021)	Okyanus Tuzu
NaCl 34,8 g KCl 1,6 g CaCl 5,8 g MgCl 9,78 g 2 L Distile Su 16,5 mL/1 L Distile Su İletkenik 827 mS Tuzluluk 0,44 ppt TDS 411 ppm	NaCl 14,6 g KCl 0,63 g CaCl 2,43 g $MgSO_4$ 4,07 g 1 L Distile Su 20 mL/980 mL Distile Su İletkenik 815 mS Tuzluluk 0,43 ppt TDS 425 ppm	Okyanus Tuzu (ReeFlowers Caledonia Sea Salt®) 0,03 g/L Distile Su İletkenik 500 mS Tuzluluk 0,26 ppt TDS 252 ppm

Deneylerde kullanılan üç farklı gelişim ortamının kimyasal bileşenleri ve ölçülen fizikokimyasal parametreleri (iletkenlik, tuzluluk, TDS) Tablo 1'de detaylandırılmıştır.
Elde edilen parametreler incelendiğinde, standart E3 ortamlarının iletkenlik (815–827 mS) ve TDS (411–425 ppm) değerleri açısından birbirine oldukça yakın olduğu görülmektedir.

Alternatif olarak hazırlanan 0.03 g/L okyanus tuzu çözeltisi ise daha düşük fizikokimyasal değerlere (500 mS iletkenlik, 0.26 ppt tuzluluk ve 252 ppm TDS) sahip olmakla birlikte, embriyonun ihtiyaç duyduğu temel iyonik dengeyi sağlayacak bileşimi bünyesinde barındırmaktadır.

İstatiksel Analiz

Tüm veriler ortalama ± standart sapma (SD) olarak ifade edilmiştir. İstatistiksel analizlerden önce varyansların homojenliği Levene testi ile değerlendirilmiştir. Gruplar arasındaki farklılıklar tek yönlü varyans analizi (ANOVA) ile belirlenmiş, ikili karşılaştırmalar için Tukey post hoc testi uygulanmıştır ($p \leq 0.05$). İstatistiksel analizler IBM SPSS Statistics 22.0 (SPSS Inc.) yazılımı ile yapılmıştır.

48. Saatte Yumurta Uzunluğunun Morfometrik Değerlendirilmesi

Embriyoların osmotik dengesini ve fiziksel gelişim süreçlerini doğrulamak amacıyla döllenmeden sonraki 48. saatte (hpf) gerçekleştirilen yumurta çapı/uzunluğu ölçümleri Tablo 2 ve Şekil 1'de sunulmuştur.

Tablo 2, döllenmeden sonraki 48. saatte farklı gelişim ortamlarında (E3 60X, E3 50X ve 0.03 g/L Okyanus Tuzu) tutulan zebra balığı yumurtalarının uzunluklarına dair morfometrik değerlendirmeyi sunmaktadır.

Ortamlara göre ölçülen ortalama yumurta uzunlukları şu şekildedir:

- **E3 Ortamı 60X:** $1040{,}1725 \pm 7{,}217\ \mu m$
- **E3 Ortamı 50X:** $1047{,}006 \pm 7{,}292\ \mu m$
- **Okyanus Tuzu (0.03 g/L):** $1057{,}187 \pm 3{,}291\ \mu m$

Gruplar arasındaki bu ölçüm farkları üzerinde gerçekleştirilen tek yönlü varyans analizi (ANOVA) sonuçlarına göre, yumurta uzunlukları açısından gruplar arasında istatistiksel açıdan anlamlı bir fark tespit edilememiştir. ($p = 0{,}159$; $p > 0{,}05$).

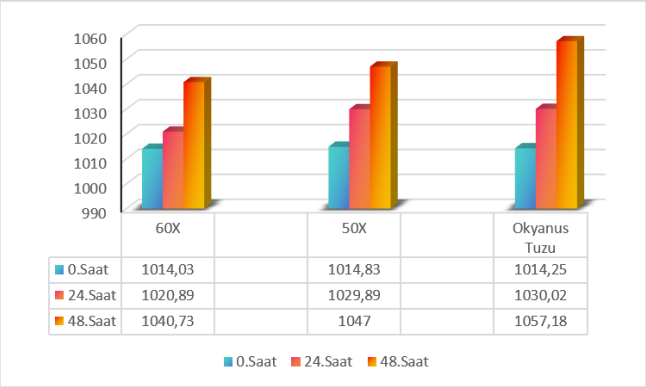
- **Ozmolarite ve İyonik Dengenin Korunması:** Yumurta çapı (uzunluğu), embriyonun fiziksel gelişimini izlemek ve ortamın ozmotik basınç dengesini doğrulamak için kritik bir parametredir2more_horiz. Ortamlar arasında istatistiksel açıdan anlamlı bir boyut farkının oluşmaması; hazırlanan tüm gelişim ortamlarının (özellikle de alternatif okyanus tuzu çözeltisinin), embriyonun ihtiyaç duyduğu osmotik ve pH dengesini 48. saatte de başarıyla koruduğunu göstermektedir.
- **Fiziksel Gelişimin Eşdeğerliği:** 48. saatteki yumurta boyutlarının birbirine son derece yakın olması, alternatif bir ortam olarak seçilen 0.03 g/L okyanus tuzu çözeltisinin, standart laboratuvar ortamları olan E3 60X ve E3 50X ile eşdeğer bir morfolojik koruma sağladığını desteklemektedir1more_horiz. Okyanus tuzu ortamı, embriyonun dış kılıfında (koryon) veya su alma/ozmotik şişme süreçlerinde herhangi bir anomaliliğe yol açmamıştır.

Tablo 2 verileri, pratik ve ekonomik bir alternatif olan okyanus tuzu çözeltisinin, zebra balığı embriyolarının erken morfolojik gelişim dönemlerinde standart E3 ortamları yerine güvenle tercih edilebileceğini deneysel olarak doğrulamaktadır.

Tablo 2. 48. Saatte Yumurta Uzunluğunun Morfometrik Değerlendirilmesi

E3 ortamı 60X	**E3 ortamı 50X**	**Okyanus Tuzu 0,03 g/L**
1040,1725±7,217 µm	1047,006±7,292 µm	1057,187±3,291 µm

Veriler ortalama ± standart sapma (SD) olarak sunulmuştur. Tek yönlü varyans analizi (ANOVA) sonuçlarına göre gruplar arasındaki farkın istatistiksel olarak anlamlı olmadığı belirlenmiştir. ($p=0{,}159$) ($p>0{,}05$).

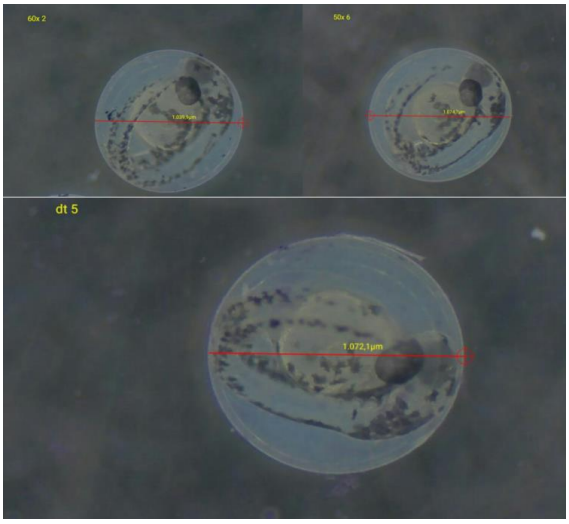


Şekil 2. Zebra Balığı Yumurta Uzunlukları

Şekil 2 (Zebra Balığı Yumurta Uzunlukları) grafiği, farklı inkübasyon ortamlarında yetiştirilen zebra balığı (*Danio rerio*) embriyolarının fiziksel gelişimini ve morfolojik özelliklerini izlemek amacıyla sistematik olarak kaydedilen yumurta çapı/uzunluğu verilerini görselleştirmektedir (Şekil 3).

Bu grafikte sunulan bulguların bilimsel yorumu ve akademik değerlendirmesi şu şekildedir:

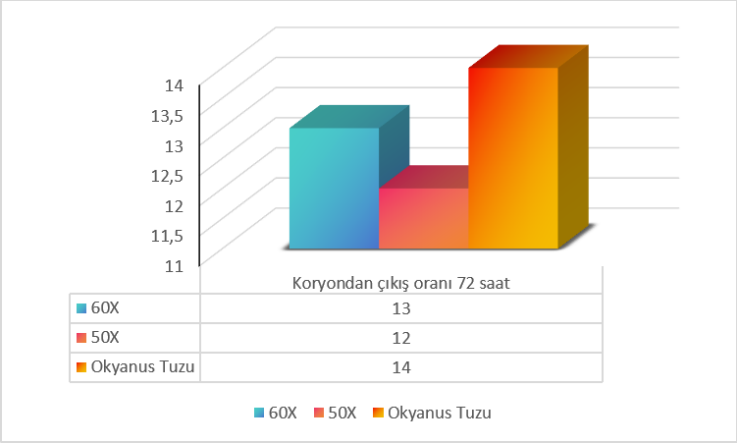
- **Gelişimsel Hacim Artışı:** Zebra balığı yumurtaları döllenme anında yaklaşık 0,7 mm (700 µm) çapındadır. Grafikte ve ilişkili morfometrik verilerde görüldüğü üzere, 48. saate gelindiğinde yumurta boyutları her üç ortamda da normal gelişimsel su alma ve büyüme süreçlerine bağlı olarak 1040 µm ile 1057 µm aralığına ulaşmıştır.
- **Gruplar Arası Boyutsal Eşdeğerlik:** Grafiğe temel oluşturan 48. saat ölçümlerine göre ortalama yumurta uzunlukları; E3 60X grubunda 1040,1725 ± 7,217 µm, E3 50X grubunda 1047,006 ± 7,292 µm ve 0.03 g/L Okyanus Tuzu grubunda ise 1057,187 ± 3,291 µm olarak kaydedilmiştir. Grupların ortalamaları ve hata payları (standart sapmaları) birbirine son derece yakın bir seyir izlemektedir.
- **İstatistiksel Analiz Sonucu:** Veriler üzerinde uygulanan tek yönlü varyans analizi (ANOVA) sonuçlarına göre, yumurta uzunlukları açısından gruplar arasında istatistiksel olarak anlamlı bir farklılık bulunmamaktadır ($p=0,159$; $p>0,05$). Bu durum, test edilen farklı tuz bileşimlerinin yumurta kılıfı (koryon) bütünlüğü ve osmotik şişme oranları üzerinde herhangi bir anomaliye veya olumsuz morfolojik sapmaya yol açmadığını kanıtlar.
- **Alternatif Ortamın Ozmotik Başarısı:** Embriyo gelişimi için ortamın iyonik dengesi ve ozmotik basınç dengesinin (ozmolaritesinin) korunması hayati önem taşır. Şekil 1'de görselleştirilen bu boyutsal stabilite, hazırlanması çok daha pratik olan 0.03 g/L okyanus tuzu çözeltisinin, standart E3 ortamları kadar başarılı bir osmotik denge ve morfolojik koruma sunduğunu deneysel olarak doğrulamaktadır.



Şekil 3. Zebra Balığı Embriyo Görseli (48 saat)

72. Saatte Koryondan Çıkış Oranları

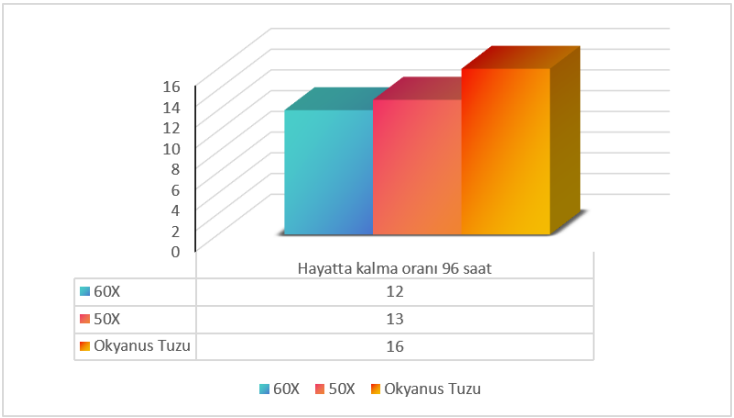
Gelişimsel sürecin başarısını ve embriyonun yumurta kılıfından sağlıklı bir şekilde kurtulma yeteneğini değerlendirmek için 72. saatte koryondan çıkış oranları izlenmiştir. Şekil 4 (Zebra Embriyo 72. Saat Koryondan Çıkış Oranı) verileri analiz edildiğinde, test edilen tüm ortamlarda embriyoların sağlıklı bir şekilde koryondan çıktığı gözlenmiştir. Bu parametre, alternatif okyanus tuzu ortamının embriyonun normal gelişim takvimini geciktirici bir etkisi olmadığını ve koryondan çıkış enzimlerinin (koriyonaz) aktivitesini olumsuz yönde etkilemediğini göstermektedir.



Şekil 4. Zebra Embriyo 72. Saat Koryondan Çıkış Oranı

96. Saat Hayatta Kalma Oranı

Şekil 5, çalışmanızda "Zebra Balığı Embriyo 96. Saat Hayatta Kalma Oranı" başlığıyla yer alan ve embriyoların farklı gelişim ortamlarındaki yaşamsal sürekliliğini gösteren kritik bir parametredir.



Şekil 5. Zebra Embriyo 96. Saat Hayatta Kalma Oranı

Şekil 5'ün grafiksel detayları veya gruplara ait tam yüzde değerleri (örneğin %95, %98 gibi net hayatta kalma oranları) metinsel olarak açıkça belirtilmemiştir. Ancak, çalışmanızın genel bulguları ve sonuçları doğrultusunda Şekil 3'ün bilimsel yorumu şu şekildedir:

- **Yaşamsal Süreklilik ve Toksisite Değerlendirmesi:** Hayatta kalma oranı, gelişim ortamlarının embriyolar üzerindeki toksik etkisini ve yaşamsal uyumluluğunu belirleyen en temel parametredir. 96. saat (96 hpf), zebra balığı embriyolarının koryondan çıkıp larva haline geldiği dönemde morfolojik gelişimlerini ve yaşamsal sürekliliklerini değerlendirmek için kritik bir süredir.
- **Gelişimsel Farklılık Oluşmaması:** Sistematik olarak kaydedilen hayatta kalma oranı, koryondan çıkış oranı ve yumurta çapı gibi parametreler incelendiğinde; pratik bir alternatif olarak seçilen 0.03 g/L okyanus tuzu çözeltisinin, standart laboratuvar ortamları olan 60x E3 ve 50x E3 ile karşılaştırıldığında embriyo gelişiminde ve yaşamsal süreçlerinde anlamlı bir farklılık yaratmadığı tespit edilmiştir.

- **Güvenli ve Ekonomik Alternatif:** Şekil 3'te görselleştirilen bu hayatta kalma başarısı, iyonik dengesi ve ozmolaritesi (ozmotik basınç dengesi) korunduğu sürece, hazırlanması çok daha kolay ve ekonomik olan okyanus tuzu çözeltisinin, klasik izotonik standart laboratuvar ortamları yerine zebra balığı çalışmalarında güvenle tercih edilebileceğini biyolojik olarak doğrulamaktadır.

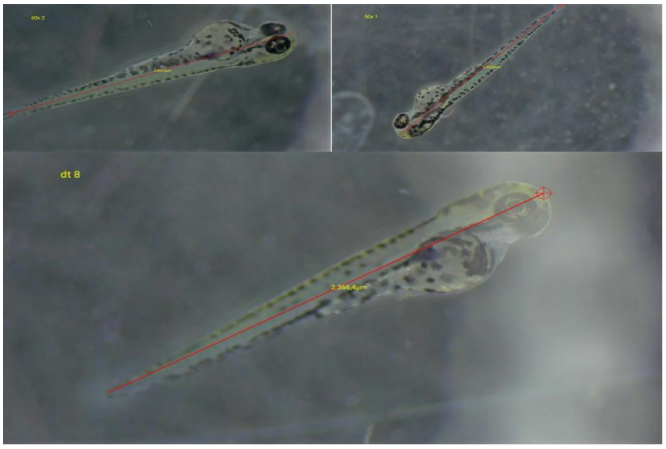
Alternatif okyanus tuzu ortamının embriyolar için standart ortamlar kadar biyouyumlu ve güvenli olduğunu, yaşamsal süreklilikte bir kayba veya olumsuzluğa yol açmadığını ortaya koymaktadır.

96. Saatte Larva Uzunluğunun Morfometrik Değerlendirilmesi

Tablo 3. 96. Saatte Larva Uzunluğunun Morfometrik Değerlendirilmesi

E3 ortamı 60X	E3 ortamı 50X	Okyanus Tuzu 0,03 g/L
2500,183±251,665 µm	2412,600±360,485 µm	2426,062±198,616 µm

Veriler ortalama ± standart sapma (SD) olarak sunulmuştur. Tek yönlü varyans analizi (ANOVA) sonuçlarına göre gruplar arasında anlamlı bir düzeyde fark bulunamamıştır. (p=0,687) (p > 0,05).



Şekil 6. 96. Saatte Larva Uzunluğunun Morfometrik Değerlendirilmesinin Görseli

İnkübasyonun son aşaması olan 96. saatte (hpf), koryondan çıkan serbest yüzen larvaların morfolojik büyüme performanslarını izlemek amacıyla morfometrik boy uzunlukları (Şekil 6) ölçülmüş ve sonuçlar Tablo 3'de özetlenmiştir.

Tablo 3, döllenmeden sonraki 96. saatte farklı inkübasyon ortamlarında (E3 60X, E3 50X ve 0.03 g/L Okyanus Tuzu) gelişen zebra balığı larvalarının boy uzunluklarının morfometrik değerlendirmesini göstermektedir.

Ortamlara göre ölçülen ortalama larva uzunlukları şu şekildedir:

- **E3 Ortamı 60X:** $2500{,}183 \pm 251{,}665\ \mu m$
- **E3 Ortamı 50X:** $2412{,}600 \pm 360{,}485\ \mu m$
- **Okyanus Tuzu (0.03 g/L):** $2426{,}062 \pm 198{,}616\ \mu m$

Elde edilen veriler üzerinde gerçekleştirilen tek yönlü varyans analizi (ANOVA) sonuçlarına göre, gruplar arasında istatistiksel olarak anlamlı bir farklılık bulunmamaktadır ($p = 0{,}687$; $p > 0{,}05$).

- **Gelişimsel Eşdeğerlik:** Üç farklı inkübasyon ortamında yetiştirilen embriyoların 96. saat sonunda ulaştıkları larva boyları birbirine oldukça yakındır. Bu durum, farklı tuz bileşimlerinin ve konsantrasyonlarının larvaların erken dönem boyca büyüme hızı üzerinde engelleyici veya hızlandırıcı belirgin bir etkisi olmadığını göstermektedir.

- **Okyanus Tuzunun Alternatif Potansiyeli:** Hazırlanması standart E3 ortamlarına kıyasla çok daha pratik ve ekonomik olan 0.03 g/L okyanus tuzu çözeltisinin, klasik izotonik laboratuvar ortamları (E3 60X ve E3 50X) ile benzer gelişimsel performansı sergilediği bu morfometrik veriyle kanıtlanmıştır.

İyonik denge korunduğu sürece, karmaşık laboratuvar protokolleri gerektirmeyen bu pratik okyanus tuzu alternatifinin, zebra balığı embriyo ve larva çalışmalarında güvenle ve başarıyla tercih edilebileceği Tablo 3 verileriyle desteklenmektedir.

SONUÇ

Elde edilen tüm morfometrik (yumurta çapı, larva uzunluğu) ve fizyolojik (koryondan çıkış, hayatta kalma) bulgular bir arada değerlendirildiğinde; hazırlanması çok daha kolay ve ekonomik olan 0.03 g/L okyanus tuzu çözeltisinin, karmaşık laboratuvar protokolleri gerektiren klasik izotonik E3 ortamları ile tamamen eş değer gelişimsel performans sergilediği deneysel olarak kanıtlanmıştır. Bu durum, pratik okyanus tuzu alternatifinin zebra balığı embriyo ve larva toksisite/gelişim çalışmalarında güvenilir bir gelişim ortamı olarak tercih edilebileceğini göstermektedir.

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ULTRASONİK KAVİTASYON DESTEKLİ $Bİ_2O_3/CEO_2$ HİBRİT KAPLI KENEVİR KUMAŞLARIN GELİŞTİRİLMESİ VE ÇOK İŞLEVLİ RADYASYON ZIRHLAMA PERFORMANSININ İNCELENMESİ

DEVELOPMENT OF ULTRASONIC CAVITATION-ASSISTED BI_2O_3/CEO_2 HYBRID-COATED HEMP FABRICS AND INVESTIGATION OF THEIR MULTIFUNCTIONAL RADIATION SHIELDING PERFORMANCE

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ÖZET
Sürdürülebilir, hafif ve esnek koruyucu tekstillerin geliştirilmesi, geleneksel ağır radyasyon zırhlama malzemelerine yenilikçi alternatifler sunması bakımından kritik önem taşımaktadır. Kenevir lifleri; düşük yoğunlukları ve yüksek mekanik mukavemetlerinin yanı sıra, yapılarındaki lignin ve kromoforik bileşenlerin sunduğu doğal UV absorpsiyon yeteneği sayesinde fonksiyonel koruyucu tekstiller için ideal bir altlık oluşturmaktadır. Bu çalışmada, kenevir kumaşların mevcut UV koruma potansiyelini artırmak ve iyonlaştırıcı radyasyona karşı koruyuculuk kazandırmak amacıyla Bi_2O_3/CeO_2 hibrit seramik kaplamalar ultrasonik banyo yöntemiyle kumaş yüzeyine entegre edilmektedir. Yüksek atom numarasına sahip Bi_2O_3 fazının X-ışını/gama radyasyon sönümleme kapasitesi ile CeO_2 fazının UV absorpsiyon özelliğinin sinerjistik birleşimi, çok işlevli bir koruyucu yüzey mimarisi sunmaktadır. Yöntem kapsamında oluşan akustik kavitasyon ve mikro-jet etkileri, nanopartiküllerin kenevirin mikro-gözenekli lif yapısına derinlemesine penetre olmasını ve kimyasal bağlayıcıya ihtiyaç duyulmaksızın fiziksel olarak tutunmasını sağlamaktadır. Akustik enerjinin lifler arası mikro-kanallarda yarattığı yerel basınç dalgaları, hibrit seramik parçacıkların kumaş yüzeyinde homojen ve aglomerasyonsuz bir dağılım sergilemesini mümkün kılmaktadır. Çalışmada, Bi_2O_3, CeO_2 ve hibrit Bi_2O_3/CeO_2 kaplı kenevir kumaşların yüzey morfolojisi SEM–EDS, kristal yapısı XRD ve kumaş üzerindeki kaplama tutunma miktarları gravimetrik tartım analizleriyle karakterize edilmektedir. Ayrıca, kaplamaların lif yüzeyine adezyon kararlılığı ve kullanım ömrü mekanik aşınma ve yıkama testleri ile değerlendirilmektedir. Foton sönümleme ve UV koruma performansları ise sırasıyla X-ışını zayıflatma ve UV–Vis/UPF spektroskopisi ölçümleriyle analiz edilmektedir. Bu yaklaşım, kenevir kumaşın doğal yapısı ile seramik nanoyapıların tamamlayıcı özelliklerini birleştirerek hafif, sürdürülebilir ve yüksek performanslı bir radyasyon koruyucu tekstil konsepti ortaya koymaktadır.
Anahtar Kelimeler: Kenevir kumaş, Bi_2O_3/CeO_2 hibrit kaplama, ultrasonik kavitasyon, UV koruma, radyasyon zırhlama

ABSTRACT
Developing sustainable, lightweight, and flexible protective textiles is of critical importance for offering innovative alternatives to traditional heavy radiation shielding materials. Hemp fibers provide an ideal substrate for functional protective textiles due to their low density and high mechanical strength, combined with the inherent UV absorption capability provided by lignin and chromophoric components in their lignocellulosic structure. In this study, Bi_2O_3/CeO_2 hybrid ceramic coatings are integrated onto hemp fabric surfaces via an ultrasonic bath method to enhance their existing UV protection potential and impart shielding capabilities against ionizing radiation. The synergistic combination of the high-atomic-number Bi_2O_3 phase (for X-ray/gamma-ray attenuation) and the CeO_2 phase (for UV absorption) provides a multifunctional protective surface architecture. Acoustic cavitation and micro-jet phenomena generated during the ultrasonic process drive the nanoparticles deep into the porous micro-fibrillar channels of hemp, achieving physical interlocking without the need for chemical binders. The localized pressure waves induced by acoustic energy within the inter-fiber micro-channels enable a highly uniform and agglomeration-free dispersion of the hybrid ceramic particles across the fabric matrix. The surface morphology, crystalline structure, and coating add-on percentage of the mono (Bi_2O_3, CeO_2) and hybrid (Bi_2O_3/CeO_2) coated hemp fabrics are systematically characterized using SEM–EDS, XRD, and gravimetric analyses.

Furthermore, the interfacial adhesion stability and durability of the coatings against the fiber substrate are assessed through mechanical abrasion and washing resistance tests. Photon attenuation and UV protection performances are evaluated via X-ray attenuation measurements and UV–Vis/UPF spectroscopy, respectively. This approach presents a lightweight, sustainable, and high-performance radiation protective textile concept by merging the natural advantages of hemp with the complementary functionalities of ceramic nanostructures.

Keywords: Hemp fabric, Bi_2O_3/CeO_2 hybrid coating, acoustic cavitation, UV protection, radiation shielding

PARAMETRİK SİGORTANIN SİGORTA SÖZLEŞMESİ OLARAK NİTELENDİRİLMESİ: TTK M. 1401'İN AMAÇSAL VE İŞLEVSEL YORUMU

THE LEGAL CHARACTERIZATION OF PARAMETRIC INSURANCE AS AN INSURANCE CONTRACT: A PURPOSIVE AND FUNCTIONAL INTERPRETATION OF ARTICLE 1401 OF THE TURKISH COMMERCIAL CODE

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ÖZET

Parametrik sigortanın Türk sigorta hukuku bakımından ortaya çıkardığı temel sorun, fiilî zararın bireysel olarak tespit edilmediği ve sigortacının ödeme borcunun önceden belirlenmiş objektif bir parametrenin gerçekleşmesine bağlandığı bu modelin, Türk Ticaret Kanunu m. 1401 anlamında sigorta sözleşmesi olarak nitelendirilip nitelendirilemeyeceğidir. Geleneksel zarar sigortasının zarar tespiti ve tazmin esaslı yapısından ayrılan parametrik model, sigorta sözleşmesinin kanuni tanımının yeni nesil risk transfer araçları karşısında ne ölçüde esnek yorumlanabileceği sorusunu gündeme getirmektedir.

Parametrik sigortanın hukuki niteliği, TTK m. 1401'in lafzıyla sınırlı bir değerlendirme yerine, sigorta sözleşmesinin amacı ve ekonomik işlevi dikkate alınarak incelenmelidir. Parametrik sigortada da prim karşılığında tesadüfi bir rizikonun ekonomik sonuçlarının üstlenilmesi ve hukuken korunmaya değer, para ile ölçülebilir bir menfaate koruma sağlanması söz konusudur. Ödeme miktarının riziko sonrasında gerçekleştirilecek bireysel zarar hesabına değil, sözleşmede önceden belirlenen tetikleyiciye dayanması ise kullanılan risk transfer tekniğinin farklılığını göstermektedir. Bu farklılığın tek başına sözleşmenin sigorta niteliğini ortadan kaldırmaması gerektiği savunulmaktadır.

Bununla birlikte amaçsal ve işlevsel yorum, belirli bir parametrenin gerçekleşmesine bağlı her ödeme taahhüdünün sigorta olarak kabul edilmesi anlamına gelmemelidir. Parametrik sözleşmenin spekülatif bir işlemden ayrılabilmesi için tesadüfi bir rizikonun varlığı, bu rizikoya maruz kalan hukuken korunabilir ekonomik bir menfaat ve sözleşmenin esas itibarıyla söz konusu rizikonun ekonomik sonuçlarına karşı koruma sağlama amacı taşıması aranmalıdır.

Çalışmanın temel tezi, parametrik sigortanın ne geleneksel zarar sigortasının yalnızca farklı bir ödeme tekniğine sahip görünümü ne de sigorta hukukundan bağımsız bir finansal araç olduğudur. TTK m. 1401, sigorta hukukunun değişen riskler ve teknolojik gelişmeler karşısındaki dinamik niteliği gözetilerek amaçsal ve işlevsel biçimde yorumlanmalıdır. Böyle bir yaklaşım, parametrik sigortanın Türk sigorta hukuku içerisinde konumlandırılmasına imkân verirken, sigorta ile spekülatif risk transfer işlemleri arasındaki hukuki sınırın korunmasını da mümkün kılmaktadır.

Anahtar Kelimeler: Parametrik sigorta, sigorta sözleşmesi, TTK m. 1401, amaçsal yorum, sigortalanabilir menfaat, risk transferi.

ABSTRACT

The principal issue raised by parametric insurance under Turkish insurance law concerns whether a model in which the actual loss is not individually assessed and the insurer's payment obligation is instead linked to the occurrence of a predetermined objective parameter may nevertheless be characterized as an insurance contract within the meaning of Article 1401 of the Turkish Commercial Code (TCC). By departing from the loss assessment and indemnification structure traditionally associated with indemnity insurance, the parametric model raises the broader question of how flexibly the statutory definition of an insurance contract should be interpreted in the face of emerging risk-transfer mechanisms.

The legal characterization of parametric insurance should therefore be determined not solely through a literal reading of Article 1401 TCC, but also by reference to the purpose and economic function of the insurance contract. Parametric insurance likewise involves, in return for a premium, the assumption of the economic consequences of a fortuitous risk and the protection of a legally recognized and economically measurable interest. The fact that the amount payable is determined not through an individual assessment of loss following the occurrence of the insured event, but by reference to a contractually predetermined trigger, merely reflects a different technique of risk transfer. It is argued that this distinction should not, in itself, deprive the contract of its character as insurance.

A purposive and functional interpretation, however, should not result in every undertaking to make payment upon the occurrence of a specified parameter being classified as insurance. In order to distinguish a parametric insurance contract from a speculative transaction, there must be a fortuitous risk, a legally protectable economic interest exposed to that risk, and a contractual purpose primarily directed at providing protection against the economic consequences of such risk.

The central argument of this study is that parametric insurance should be regarded neither as a mere variation of traditional indemnity insurance employing a different payment technique nor as a financial instrument entirely detached from insurance law. Article 1401 TCC should be interpreted purposively and functionally in light of the dynamic nature of insurance law and its need to respond to evolving risks and technological developments. Such an approach enables parametric insurance to be situated coherently within Turkish insurance law while simultaneously preserving the legal boundary between insurance and speculative risk-transfer transactions.

Keywords: Parametric insurance, insurance contract, Article 1401 TCC, purposive interpretation, insurable interest, risk transfer.

KAHRAMANMARAŞ GASTRONOMİK MİRASININ DENEYİM DEĞERİNE DÖNÜŞÜMÜNDE HİKÂYE ANLATICILIĞI: BİR MODEL ÖNERİSİ

STORYTELLING IN THE TRANSFORMATION OF KAHRAMANMARAŞ'S GASTRONOMIC HERITAGE INTO EXPERIENTIAL VALUE: A MODEL PROPOSAL

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ÖZET

Gastronomi turizminde yerel yiyecek ve içecekler, yalnızca tüketilen ürünler olmanın ötesinde, destinasyonların kültürel kimliğini, yerel yaşam biçimini ve geçmişten günümüze aktarılan geleneksel bilgi ve pratikleri deneyimlemeye olanak sağlayan önemli turistik kaynaklar hâline gelmiştir. Bu bağlamda gastronomik mirasın turizm değerinin artırılması, yalnızca ürünün fiziksel ve duyusal özelliklerinin öne çıkarılmasına değil, ürünün arkasındaki kültürel anlamların turist tarafından anlaşılmasına ve deneyimlenmesine bağlıdır. Bu çalışmanın amacı, Kahramanmaraş'ın gastronomik mirasının hikâye anlatıcılığı aracılığıyla turist açısından deneyim değerine dönüşme sürecini açıklayan kavramsal bir model geliştirmektir. Kavramsal araştırma niteliğindeki bu çalışma, Jaakkola'nın (2020) kavramsal model geliştirme yaklaşımı doğrultusunda tasarlanmış ve modelin oluşturulmasında bütünleştirici literatür incelemesinden yararlanılmıştır. Bu doğrultuda gastronomi turizmi ve gastronomik deneyim, gastronomik miras, gastronomik hikâye anlatıcılığı, kültürel anlamlandırma, duygusal bağ, deneyim değeri ve destinasyon bağlılığına ilişkin literatür bir araya getirilerek Kahramanmaraş bağlamında değerlendirilmiştir. Önerilen model; "gastronomik miras", "hikâye anlatıcılığı", "kültürel anlamlandırma", "duygusal bağ", "deneyim değeri" ve "destinasyon bağlılığı" şeklinde ardışık bir ilişki üzerine kurulmuştur. Modelde gastronomik hikâye anlatıcılığı, gastronomik mirasın taşıdığı üretim bilgisi, geleneksel uygulamalar, ritüeller, yerel aktörler, toplumsal pratikler ve kolektif hafızanın turist deneyimine aktarılmasını sağlayan temel mekanizma olarak ele alınmaktadır. Bu aktarımın turistin gastronomik mirası kültürel açıdan anlamlandırmasını, destinasyon ve yerel kültürle duygusal bağ geliştirmesini ve gastronomik deneyimi daha anlamlı, özgün ve hatırlanabilir olarak değerlendirmesini sağlayabileceği öne sürülmektedir. Buna bağlı olarak deneyim değerinin destinasyon bağlılığını güçlendirebileceği varsayılmaktadır. Çalışmada ayrıca yerel kültür ve kimlik, misafirperverlik, mekân ve atmosfer, turist özellikleri, dijital medya ve tanıtım ile sürdürülebilirlik, modelin işleyişini şekillendiren Kahramanmaraş'a özgü bağlamsal faktörler olarak ele alınmıştır. Çalışmanın sonucunda gastronomik mirasın ürün odaklı tanıtımın ötesine geçirilerek hikâye ve deneyim temelli biçimde değerlendirilmesinin Kahramanmaraş gastronomi turizminin geliştirilmesine katkı sağlayabileceği ileri sürülmektedir. Modelin ampirik olarak test edilmemiş olması nedeniyle gelecekteki araştırmalarda önerilen ilişkilerin nicel veya nitel yöntemlerle sınanması önerilmektedir.

Anahtar Kelimeler: Gastronomik miras, hikâye anlatıcılığı, deneyim değeri, destinasyon bağlılığı, Kahramanmaraş.

ABSTRACT

In gastronomy tourism, local food and beverages have evolved beyond being merely consumed products and have become important tourism resources that enable visitors to experience the cultural identity of destinations, local ways of life, and traditional knowledge and practices transmitted from the past to the present. In this context, enhancing the tourism value of gastronomic heritage depends not only on highlighting the physical and sensory characteristics of food products but also on enabling tourists to understand and experience the cultural meanings underlying these products. The aim of this study is to develop a conceptual model explaining the process through which Kahramanmaraş's gastronomic heritage is transformed into experiential value for tourists through storytelling. This conceptual study was designed in accordance with Jaakkola's (2020) conceptual model development approach, and an integrative literature review was employed in constructing the model. Accordingly, the literature on gastronomy tourism and gastronomic experience, gastronomic heritage, gastronomic storytelling, cultural meaning-making, emotional attachment, experiential value, and destination loyalty was integrated and evaluated within the context of Kahramanmaraş.

The proposed model is based on a sequential relationship comprising “gastronomic heritage,” “storytelling,” “cultural meaning-making,” “emotional attachment,” “experiential value,” and “destination loyalty”. In the model, gastronomic storytelling is considered the primary mechanism through which the production knowledge, traditional practices, rituals, local actors, social practices, and collective memory embedded in gastronomic heritage are conveyed to tourists. It is proposed that this process may enable tourists to interpret gastronomic heritage from a cultural perspective, develop an emotional attachment to the destination and local culture, and perceive their gastronomic experiences as more meaningful, authentic, and memorable. Accordingly, experiential value is assumed to strengthen destination loyalty. The study also considers local culture and identity, hospitality, place and atmosphere, tourist characteristics, digital media and promotion, and sustainability as context-specific factors shaping the functioning of the model in Kahramanmaraş. The study concludes that evaluating gastronomic heritage through a story- and experience-based approach, rather than focusing solely on product-oriented promotion, may contribute to the development of gastronomy tourism in Kahramanmaraş. Since the proposed model has not yet been empirically tested, future research is recommended to examine the proposed relationships using quantitative or qualitative methods.
Keywords: Gastronomic heritage, storytelling, experiential value, destination loyalty, Kahramanmaraş.

GİRİŞ

Gastronomi turizmi, yiyecek ve içeceklerin yalnızca tüketim nesneleri olarak değerlendirildiği bir anlayıştan uzaklaşarak, turistlerin destinasyonların kültürel kimliğini, yerel yaşam biçimini ve özgünlüklerini deneyimlemelerine aracılık eden çok boyutlu bir alan hâline gelmiştir. Yerel yiyecekler; üretim biçimleri, kullanılan hammaddeler, geleneksel bilgi ve beceriler, tüketim pratikleri ve bunların etrafında gelişen sosyal ilişkiler aracılığıyla belirli bir coğrafyanın kültürel özelliklerini görünür kılabilmektedir. Bu nedenle gastronomik deneyimin değeri yalnızca yiyeceğin lezzeti, görünümü veya fiziksel özellikleri üzerinden açıklanamamakta; turistin yerel yiyecekle kurduğu sosyal etkileşim, edindiği bilgi, deneyimin özgünlüğü, duygusal boyutu ve hatırlanabilirliği de deneyimin niteliğini belirlemektedir (Bessière & Tibère, 2013; Ellis vd., 2018; Badu-Baiden vd., 2022a). Bu çerçevede gastronomik miras, belirli bir yere ait yiyecek ve içeceklerin yanı sıra bunların üretim ve hazırlanma tekniklerini, geleneksel bilgi ve becerileri, tüketim biçimlerini, ritüelleri ve toplumsal pratikleri kapsayan dinamik bir yapı olarak değerlendirilmektedir (Bessière, 1998). Dolayısıyla gastronomik mirasın turizm açısından değer üretmesi, yalnızca miras unsurlarının turistlere sunulmasına değil, bu unsurların ait oldukları yer, insanlar, kültür ve geçmiş ile kurduğu ilişkinin turist tarafından anlaşılmasına bağlıdır. Gastronomik mirasın nasıl temsil edildiği ve hangi anlamlarla aktarıldığı bu noktada önem kazanmakta; gastronomik hikâye anlatıcılığı, söz konusu kültürel anlamların turist deneyimine aktarılmasını sağlayabilecek önemli bir araç olarak öne çıkmaktadır.

Hikâye anlatıcılığı, gastronomik ürünün geçmişini, üretim sürecini, üreticilerini, geleneksel uygulamalarını ve yerel toplum açısından taşıdığı anlamları bütünlüklü bir anlatı içerisinde bir araya getirerek turistin gastronomik mirasla kurduğu ilişkiyi derinleştirebilir. Nitekim gastronomi turizmi ve hikâye anlatıcılığı arasındaki ilişkiye yönelik çalışmalar, yiyecek tüketiminin aynı zamanda bir hikâyenin ve kültürel anlamın deneyimlenmesine dönüşebileceğini ve anlatıların gastronomik deneyimi zenginleştirebileceğini ortaya koymaktadır (Kardeş Çolakoğlu & Sarıışık, 2021; Martins vd., 2023; Rahayuningsih vd., 2025). Hikâye aracılığıyla gastronomik mirasın kültürel bağlamının anlaşılması, turistin destinasyonla bilişsel ve duygusal düzeyde daha güçlü bir ilişki kurmasına ve deneyimi daha anlamlı ve hatırlanabilir biçimde değerlendirmesine katkı sağlayabilir. Bu noktadan hareketle bu çalışmada, Kahramanmaraş’ın gastronomik mirasının turist açısından deneyim değerine dönüşümünde hikâye anlatıcılığının rolü ele alınmaktadır. Çalışmada gastronomik miras; yalnızca belirli yiyecek ve içeceklerden oluşan bir ürün grubu olarak değil, geleneksel üretim bilgisi ve becerileri, üretim ve tüketim pratikleri, ritüeller, toplumsal ilişkiler, yerel aktörler ve kolektif hafıza ile birlikte değerlendirilmektedir. Bu doğrultuda çalışma, gastronomik mirasın hikâye anlatıcılığı yoluyla turist tarafından kültürel olarak anlamlandırılması, bu anlamlandırmanın duygusal bağ oluşturması ve bunun deneyim değerine ve destinasyon bağlılığına nasıl dönüşebileceğini açıklayan kavramsal bir model önermektedir.

KAVRAMSAL ÇERÇEVE

Gastronomi Turizmi ve Gastronomik Deneyim

Gastronomi turizmi, yiyecek ve içeceklerin yalnızca tüketim nesnesi olarak değil, destinasyonların kültürel kimliğini, yerel yaşam biçimini ve özgünlüğünü deneyimlemeye aracılık eden turistik kaynaklar olarak değerlendirildiği bir alan hâline gelmiştir. Ayrıca gastronomi kültür, otantiklik, pazarlama ve destinasyon gibi temalar etrafında şekillenmekte ve yiyecekler, turist ile destinasyon arasındaki kültürel etkileşimin önemli araçlarından biri olarak kabul edilmektedir (Ellis vd., 2018).

Yerel yiyeceklerin destinasyon deneyimindeki rolü, gastronominin destinasyon imajı ve davranışsal niyetlerle ilişkisi üzerinden ortaya konulmaktadır. Diğer bir ifade ile destinasyonların yiyecek imajının ziyaret niyeti üzerinde olumlu bir etkiye sahip olduğu bilinmektedir (Karim & Chi, 2010). Ek olarak Bessière & Tibère (2013) yerel mutfağın turist açısından gündelik yaşamdan farklılaşan duyusal ve kültürel bir deneyim sunduğunu vurgulamaktadır. Bu nedenle gastronomi turizminde deneyimin değeri yalnızca yiyeceğin lezzeti veya fiziksel özellikleriyle açıklanamamaktadır.

Turistin yerel yiyecekle kurduğu sosyal etkileşim, öğrendiği bilgiler, deneyimin özgünlüğü, duygusal boyutu ve hatırlanabilirliği de gastronomik deneyimin niteliğini belirlemektedir. Nitekim Badu-Baiden vd. (2022a), yerel yiyecek tüketiminin çok boyutlu ve hatırlanabilir bir deneyime dönüşebildiğini ve bu deneyimin destinasyon sadakatini açıklamada anlamlı bir güce sahip olduğunu ortaya koymuştur. Dolayısıyla gastronomi turizmi açısından temel mesele yalnızca “turiste ne yedirildiği” değil, “turistin bu yiyeceği nasıl deneyimlediği ve ona ne anlam yüklediği” hâline gelmektedir.

Gastronomik Miras ve Kültürel Anlam

Gastronomik miras, belirli bir yere ait yiyecek ve içeceklerin yanı sıra bunların üretim ve hazırlanma tekniklerini, geleneksel bilgi ve becerileri, tüketim biçimlerini, ritüelleri ve toplumsal pratikleri kapsayan çok boyutlu bir yapı olarak değerlendirilmektedir. Bessière (1998), gastronomik mirasın yerel kimliğin oluşumunda önemli bir unsur olduğunu ve geleneksel yiyeceklerin geçmişten aktarılan bilgi ve becerilerin yeniden yorumlanması yoluyla turistik bir kaynağa dönüşebildiğini belirtmektedir. Bu açıdan gastronomik miras statik bir ürün topluluğu değildir.

Turizmde hangi unsurların öne çıkarıldığı, nasıl temsil edildiği ve bu unsurlara hangi anlamların yüklendiği büyük önem taşımaktadır. Örneğin Avieli (2013), Vietnam’ın Hoi An şehrindeki yerel yemek ve gastronomik mirasın turizm bağlamında nasıl seçilebildiğini, dönüştürülebildiğini ve yeniden anlamlandırılabildiğini ortaya koymuştur. Güncel araştırmalar, gastronomik miras deneyimlerinin turistlerin kültürel algıları ve destinasyonla kurdukları bağlar açısından kritik bir role sahip olduğunu göstermektedir. Bu kapsamda Chu vd. (2026), çok boyutlu gastronomik miras deneyimlerinin; kültürel benzersizlik, kültürel gurur ve kültürel kimlik unsurları aracılığıyla destinasyon markasıyla etkileşimi güçlendirdiğini tespit etmiştir.

Yukarıda verilen bilgiler doğrultusunda gastronomik mirasın turizm açısından değerinin, yalnızca ürünün varlığından değil, ürün ile yer, insan, kültür ve geçmiş arasındaki ilişkinin turist tarafından anlaşılabilmesinden kaynaklandığı söylenebilir.

Gastronomik Hikâye Anlatıcılığı

Gastronomik mirasın taşıdığı kültürel anlamların turistlere aktarılmasında hikâye anlatıcılığı önemli bir araçtır. Hikâye anlatımı, gastronomik ürünün geçmişini, üretim sürecini, üreticilerini, geleneksel uygulamalarını ve yerel toplum açısından taşıdığı anlamları bir anlatı içerisinde bir araya getirerek turistin ürünle kurduğu ilişkiyi derinleştirebilir.

Martins vd. (2023), gastronomi turizmi ile yerel hikâyeler ve gelenekler arasındaki ilişkiyi inceleyerek gastronomik hikâye anlatıcılığına yönelik kavramsal bir çerçeve geliştirmiştir. Çalışmada yiyecek tüketiminin aynı zamanda hikâye tüketimi anlamına gelebileceği ve hikâye anlatıcılığının gastronomik deneyimi zenginleştirebileceği ileri sürülmektedir. Benzer biçimde Kardeş Çolakoğlu ve Sarıışık (2021), yerel gastronomi ürünlerine ilişkin hikâyelerin destinasyon pazarlamasında kullanılabileceğini ve hikâyelerin yerel yiyeceklerin kültürel bağlamını, özgünlüğünü ve hatırlanabilirliğini güçlendirebileceğini tartışmaktadır. Rahayuningsih vd. (2025) ise geleneksel yiyeceklerin hikâyeleştirilmesiyle turistlerin yalnızca yiyeceği tatmalarının değil, yiyeceğin kültür, gelenek, hammadde ve üretim süreçleriyle ilişkisini öğrenmelerinin sağlanabileceğini göstermiştir.

Deneyim Değeri ve Destinasyon Bağlılığı

Deneyim değeri, turistin bir deneyim sonucunda elde ettiği faydayı yalnızca işlevsel özellikler üzerinden değil, deneyimin duygusal, estetik, bilişsel ve sosyal boyutları üzerinden değerlendirmesini ifade etmektedir. Mathwick vd. (2001), deneyimsel değerin estetik, eğlence, hizmet mükemmelliği ve tüketicinin deneyime yaptığı yatırım gibi farklı boyutlardan oluşabileceğini ortaya koymuştur.

Gastronomi turizmi bağlamında deneyim değeri, yiyeceğin fiziksel özelliklerinin yanı sıra mekân, sunum, öğrenme, sosyal etkileşim, otantiklik ve hatırlanabilirlik gibi unsurlarla şekillenmektedir. Örneğin Tsai & Wang (2016)'nın gastronomi turizminde deneyim değerini inceleyen çalışması, deneyimsel değerin destinasyonun yiyecek imajının oluşumunda rol oynadığını ve yiyecek imajının davranışsal niyetlerle ilişkili olduğunu göstermektedir. Hsu vd. (2021) de yiyecek festivallerinde deneyimsel değerin memnuniyet, duygusal tepkiler ve sadakat ile ilişkili olduğunu ortaya koymuştur.

Gastronomik deneyimin destinasyon bağlılığı üzerindeki potansiyel etkisi özellikle hatırlanabilir deneyimler üzerinden açıklanmaktadır. Badu-Baiden vd. (2022b), yerel gastronomi deneyiminin farklı boyutlarının belirli koşullarda destinasyon sadakatiyle ilişkili olduğunu göstermiştir. Türkiye'de yapılan bir araştırmaya göre, Kahramanmaraş özelinde gastronomik imajın genel destinasyon imajını olumlu yönde etkilediği ve ziyaretçilerin şehri tekrar tercih etme niyetini güçlendirdiği görülmüştür. Bu doğrultuda, şehirde deneyimlenen unutulmaz yerel gastronomi unsurlarının destinasyon sadakati üzerinde pozitif bir etkisi bulunmaktadır (Kara, 2025).

Bu çerçevede literatür, gastronomik mirasın kültürel anlamlarının hikâye anlatıcılığı yoluyla aktarılmasının turistin bilişsel ve duygusal katılımını güçlendirebileceğini; bunun da daha anlamlı ve hatırlanabilir bir gastronomik deneyime, dolayısıyla destinasyonla daha güçlü bir ilişkiye dönüşebileceğini göstermektedir.

YÖNTEM

Araştırmanın Amacı ve Kapsamı

Bu çalışmanın amacı, Kahramanmaraş'ın gastronomik mirasının hikâye anlatıcılığı aracılığıyla turist açısından deneyim değerine dönüşme sürecini açıklayan kavramsal bir model geliştirmektir. Çalışmada gastronomik miras yalnızca yiyecek ve içeceklerden oluşan bir ürün grubu olarak değil; geleneksel üretim bilgisi ve becerileri, üretim ve tüketim pratikleri, ritüeller, toplumsal ilişkiler, yerel aktörler ve kolektif hafızayla birlikte ele alınmaktadır. Bu doğrultuda çalışma, gastronomik mirasın nasıl anlatılabileceği ve bu anlatının turist deneyimini nasıl derinleştirebileceği sorusuna odaklanmaktadır. Çalışmanın kapsamını gastronomik miras, gastronomik hikâye anlatıcılığı, kültürel anlamlandırma, duygusal bağ, deneyim değeri ve destinasyon bağlılığı kavramları oluşturmaktadır.

Araştırmanın Tasarımı ve Kavramsal Modelin Geliştirilmesi

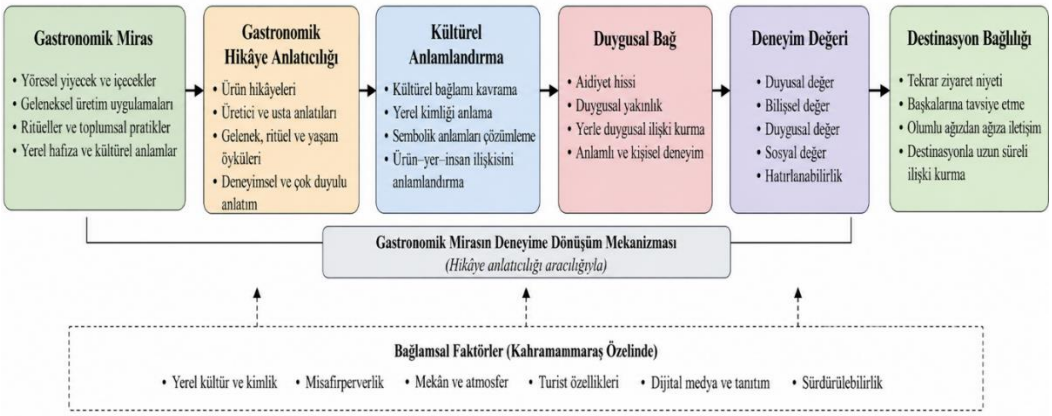
Kavramsal bir araştırma olan bu çalışma, mevcut literatürdeki kavram ve ilişkilerin sistematik biçimde bir araya getirilmesi yoluyla yeni açıklamalar ve modeller geliştirmeyi amaçlayan Jaakkola'nın (2020) model geliştirme yaklaşımı doğrultusunda tasarlanmıştır. Modelin geliştirilmesinde ise bütünleştirici literatür incelemesinden yararlanılmıştır. Torraco'ya (2005) göre bütünleştirici literatür incelemesi, farklı araştırma alanlarında ortaya konulan kavram ve bulguların sentezlenmesine ve mevcut bilgi birikiminden yeni bir kavramsal bakış açısı geliştirilmesine olanak sağlamaktadır. Bu doğrultuda öncelikle gastronomi turizmi ve gastronomik deneyim literatürü incelenmiş; ardından gastronomik mirasın kültürel kimlik ve destinasyonla ilişkisi ele alınmıştır. Sonraki aşamada gastronomik hikâye anlatıcılığına ilişkin çalışmalar değerlendirilmiş; hikâye anlatıcılığının kültürel anlamlandırma, duygusal bağ ve deneyim üzerindeki rolü araştırılmıştır. Son olarak deneyim değeri ve destinasyon bağlılığı literatürleri incelenerek kavramlar arasındaki ilişkiler bütünleştirilmiştir.

Elde edilen ilişkiler Kahramanmaraş bağlamında değerlendirilmiş ve literatürden türetilen kavramlar doğrultusunda kavramsal model oluşturulmuştur. Çalışmada herhangi bir ampirik veri toplanmamış veya model istatistiksel olarak test edilmemiştir. Bu nedenle modeldeki ilişkiler araştırma önermeleri niteliğinde olup gelecekte yapılacak ampirik çalışmalarla sınanmalıdır.

KAVRAMSAL BİR MODEL ÖNERİSİ

Bu çalışmada geliştirilen model, Kahramanmaraş'ın gastronomik mirasının turist açısından deneyim değerine dönüşümünü ürün merkezli değil, süreç ve anlam merkezli bir yaklaşımla açıklamaktadır.

Modelde gastronomik miras başlangıç noktası olarak ele alınırken, hikâye anlatıcılığı bu mirasın turist deneyimine aktarılmasını sağlayan temel mekanizma olarak konumlandırılmıştır. Hikâye anlatıcılığının ardından turistin gastronomik mirası kültürel açıdan anlamlandırması, bu anlamlandırmanın destinasyon ve yerel kültürle duygusal bir bağ oluşturması ve nihayetinde deneyimin algılanan değerini güçlendirmesi öngörülmektedir. Deneyim değerinin ise destinasyon bağlılığına yansıması beklenmektedir.



Görsel 1. Kahramanmaraş Gastronomik Mirasının Deneyim Değerine Dönüşümünde Hikâye Anlatıcılığına İlişkin Kavramsal Model

Kaynak: Yazar tarafından OpenAI ChatGPT (GPT-5.6 Luna sürümü) kullanılarak oluşturulmuştur. Görsel üretim tarihi: 10.08.2026

Görsel 1'de görüldüğü üzere modelin başlangıç noktasını gastronomik miras oluşturmaktadır. Ancak burada gastronomik miras, belirli birkaç ürünün toplamı olarak değil, yerel yiyecek ve içecekler ile bunların üretim bilgisi, geleneksel uygulamalar, ritüeller, toplumsal pratikler, yerel hafıza ve kültürel anlamlarının bütünü olarak ele alınmaktadır. Bu yaklaşım, gastronomik mirasın sosyal olarak inşa edilen ve zaman içerisinde yeniden yorumlanabilen bir yapı olduğunu savunan literatürle uyumludur (Bessière, 1998; Avieli, 2013).

Bu mirasın turist deneyimine aktarılmasında gastronomik hikâye anlatıcılığı temel mekanizma olarak konumlandırılmıştır. Hikâye anlatıcılığı aracılığıyla gastronomik mirasın yalnızca fiziksel ve duyusal özelliklerinin değil, arkasındaki insan, üretim, gelenek, mekân ve hafıza ilişkilerinin de turistlere aktarılması amaçlanmaktadır. Böylece gastronomik ürün, tüketilen bir nesne olmaktan çıkarak bir kültürel anlatının taşıyıcısına dönüşmektedir (Martins vd., 2023; Rahayuningsih vd., 2025).

Hikâye anlatıcılığının ardından modelde kültürel anlamlandırma yer almaktadır. Bu aşamada turistin gastronomik unsurun ne olduğunu öğrenmesinden daha ileri giderek, onun neden bu yere ait olduğunu, yerel toplum açısından ne ifade ettiğini ve hangi kültürel ilişkileri taşıdığını anlaması beklenmektedir. Gastronomik miras deneyimlerinin kültürel benzersizlik, kültürel gurur ve kültürel kimlik üzerinden destinasyonla etkileşimi güçlendirebildiğini ortaya koyan güncel bulgular bu ilişkiyi desteklemektedir (Chu vd., 2026).

Kültürel anlamlandırmanın bir sonraki aşamada duygusal bağ oluşturması beklenmektedir. Turistin gastronomik mirasın arkasındaki insan hikâyelerini, gelenekleri, üretim biçimlerini ve yerel yaşamı anlaması; destinasyona yönelik yakınlık, aidiyet ve duygusal ilgi geliştirmesine katkı sağlayabilir. Nitekim gastronomik hikâye anlatıcılığı ve kültürel olarak gömülü gastronomik deneyimlerin turistlerin destinasyonla duygusal bağlantılarını güçlendirebildiğini gösteren güncel bulgular bulunmaktadır (Ardika vd., 2026).

Modelin sonraki aşamasında deneyim değeri bulunmaktadır. Burada deneyim değeri, gastronomik deneyimin turist açısından yalnızca lezzet veya hizmet kalitesi bakımından değil; anlamlılık, duygusal yoğunluk, öğrenme, özgünlük, sosyal etkileşim ve hatırlanabilirlik bakımından değerlendirilmesini ifade etmektedir. Deneyimsel değerin gastronomi turizmi bağlamında destinasyonun yiyecek imajı ve davranışsal niyetlerle ilişkili olduğu daha önce ortaya konulmuştur (Mathwick vd., 2001; Tsai & Wang, 2016).

Son aşamada ise destinasyon bağlılığı yer almaktadır. Model, anlamlı ve hatırlanabilir bir gastronomik deneyimin turistin destinasyona yönelik tekrar ziyaret etme, tavsiye etme ve olumlu iletişim kurma eğilimini güçlendirebileceğini ileri sürmektedir. Hatırlanabilir yerel gastronomi deneyimlerinin destinasyon sadakatiyle ilişkili olduğunu ortaya koyan çalışmalar bu varsayımı desteklemektedir (Badu-Baiden vd., 2022a; Badu-Baiden vd., 2022b).

KAHRAMANMARAŞ'A ÖZGÜ BAĞLAMSAL FAKTÖRLER

Önerilen modelin Kahramanmaraş bağlamındaki özgünlüğünü güçlendiren unsurlardan biri, gastronomik mirasın ve hikâye anlatıcılığının destinasyonun bağlamsal özelliklerinden bağımsız değerlendirilmemesidir. Bu nedenle modelde, temel ilişkinin altında Kahramanmaraş özelinde "Bağlamsal Faktörler" başlığı altında yerel kültür ve kimlik, misafirperverlik, mekân ve atmosfer, turist özellikleri, dijital medya ve tanıtım ile sürdürülebilirlik unsurlarına yer verilmiştir. Bu faktörler modelde doğrudan yeni değişkenler olarak konumlandırılmamakta; gastronomik mirasın hikâyeleştirilmesi ve turist tarafından deneyimlenmesi sürecini şekillendiren destinasyona özgü koşullar olarak değerlendirilmektedir.

Yerel kültür ve kimlik

Gastronomik mirasın anlamlı bir hikâyeye dönüşebilmesi, anlatının yerel kültür ve kimlikle uyumlu olmasına bağlıdır. Hikâyenin yalnızca pazarlama amacıyla oluşturulması yerine, yerel halkın deneyimlediği, benimsediği ve aktardığı kültürel unsurlara dayanması, anlatının özgünlüğünü güçlendirebilir.

Misafirperverlik

Gastronomik deneyim çoğu zaman yalnızca yiyecek ile turist arasındaki bir karşılaşmadan oluşmaz. Üretici, usta, aşçı, restoran çalışanı veya yerel halk ile kurulan sosyal etkileşim de deneyimin bir parçasıdır. Dolayısıyla Kahramanmaraş'ın misafirperverlik kültürü, gastronomik hikâyelerin turistlere aktarılmasında önemli bir bağlamsal unsur olarak değerlendirilmektedir.

Mekân ve Atmosfer

Gastronomik hikâyenin nerede anlatıldığı da deneyimin anlamını etkileyebilir. Geleneksel üretim alanları, pazarlar, restoranlar, gastronomi müzeleri, yerel işletmeler veya festivaller gibi mekânlar gastronomik hikâyenin yalnızca sözlü olarak aktarılmasından ziyade yerinde deneyimlenmesine olanak sağlayabilir.

Turist Özellikleri

Her turist aynı gastronomik hikâyeyi aynı biçimde algılamayabilir. Turistin gastronomi ilgisi, kültürel merakı, seyahat motivasyonu, önceki deneyimleri ve destinasyonla ilgili bilgi düzeyi, hikâyenin anlamlandırılmasını etkileyebilecek unsurlar arasında değerlendirilebilir.

Dijital Medya ve Tanıtım

Gastronomik hikâyelerin yalnızca destinasyonda değil, seyahat öncesi ve sonrasında da aktarılması mümkündür. Sosyal medya, kısa videolar, QR kodlar, dijital arşivler, podcastler ve etkileşimli içerikler gastronomik mirasın hikâyelerinin farklı temas noktalarında turistlere ulaştırılmasını sağlayabilir. Böylece hikâye anlatıcılığı, gastronomik deneyimin yalnızca tüketim anına bağlı kalmayan bir iletişim sürecine dönüşebilir.

Sürdürülebilirlik

Gastronomik mirasın turizm amacıyla kullanılması, mirasın aşırı ticarileştirilmesi veya yerel bağlamından koparılması riskini de beraberinde getirebilir. Bu nedenle gastronomik hikâyelerin oluşturulmasında yerel aktörlerin katılımı, geleneksel bilginin korunması, üretim kaynaklarının sürdürülebilirliği ve kültürel değerlerin özgünlüğünün korunması önem taşımaktadır.

Bu bağlamsal faktörler, modeldeki temel ilişkinin yönünü doğrudan açıklayan değişkenler olmaktan ziyade, gastronomik mirasın hikâyeleştirilme biçimini ve bu hikâyenin turist tarafından deneyimlenme koşullarını etkileyebilecek destinasyon özellikleri olarak ele alınmaktadır.

SONUÇ VE ÖNERİLER

Bu çalışmada Kahramanmaraş'ın gastronomik mirasının turistler açısından deneyim değerine dönüşümünü açıklamak amacıyla kavramsal bir model geliştirilmiştir.

Model; gastronomik miras, gastronomik hikâye anlatıcılığı, kültürel anlamlandırma, duygusal bağ, deneyim değeri ve destinasyon bağlılığı arasındaki ardışık ilişki üzerine kurulmuştur.

Çalışmanın temel yaklaşımı, gastronomik mirasın sahip olduğu turizm değerinin yalnızca ürünün fiziksel veya duyusal özelliklerinden kaynaklanmadığı yönündedir. Gastronomik mirasın turist açısından daha yüksek bir değer üretebilmesi için bu mirasın arkasındaki kültürel bağlamın görünür hâle getirilmesi ve turist tarafından anlamlandırılabilmesi gerekmektedir. Bu süreçte hikâye anlatıcılığı, gastronomik miras ile turist arasında anlam ve duygu üreten temel mekanizma olarak değerlendirilmiştir.

Model doğrultusunda gastronomik hikâye anlatıcılığının kültürel anlamlandırmayı, kültürel anlamlandırmanın duygusal bağı, duygusal bağın deneyim değerini ve deneyim değerinin destinasyon bağlılığını güçlendirebileceği öne sürülmüştür. Böylece gastronomik miras ile destinasyon bağlılığı arasındaki ilişki doğrudan değil, birbirini izleyen bilişsel, duygusal ve deneyimsel süreçler üzerinden açıklanmaktadır.

Kahramanmaraş açısından değerlendirildiğinde bu yaklaşım, gastronomik mirasın yalnızca ürün temelli bir tanıtım anlayışıyla ele alınmasının ötesine geçmektedir. Gastronomik ürünlerin üretim biçimleri, geleneksel bilgi ve beceriler, yerel aktörler, toplumsal pratikler, ritüeller ve yerel hafıza ile birlikte değerlendirilmesi; gastronominin kentin kültürel kimliğinin bir parçası olarak deneyimlenmesine olanak sağlayabilir. Bu doğrultuda Kahramanmaraş gastronomi turizminin geliştirilmesine yönelik olarak öncelikle gastronomik miras envanterinin yalnızca ürün odaklı değil, hikâye odaklı biçimde oluşturulması önerilebilir. Envanter çalışmasında bir ürünün adı ve özelliklerinin yanında üretim hikâyesi, üreticileri, geleneksel bilgi ve becerileri, ritüelleri, kullanım bağlamı ve yerel toplum açısından anlamı da kayıt altına alınmalıdır.

İkinci olarak, gastronomi turizmi faaliyetlerinde yerel anlatıcıların ve kültürel taşıyıcıların daha etkin biçimde kullanılması önerilmektedir. Üreticiler, ustalar, aşçılar, yerel halk ve geleneksel bilgiye sahip kişiler gastronomik hikâyelerin temel aktörleri hâline getirilebilir. Üçüncü olarak gastronomi rotaları, festivaller, gastronomik atölyeler, müzeler ve üretici ziyaretleri gibi turistik faaliyetlerin ürün sunumunun ötesine geçirilerek hikâye ve deneyim temelli olarak tasarlanması önerilmektedir. Böylece turist yalnızca ürünü tüketen değil, üretim sürecini gören, hikâyeyi dinleyen, yerel aktörlerle etkileşim kuran ve mümkün olduğunda üretim sürecine katılan aktif bir deneyimleyici hâline gelebilir.

Dördüncü olarak dijital teknolojilerden yararlanılarak gastronomik hikâyelerin seyahat öncesi, seyahat sırası ve seyahat sonrasında turistlere aktarılması sağlanabilir. QR kodlar, kısa videolar, podcastler ve dijital hikâye haritaları bu amaçla kullanılabilecek araçlar arasında değerlendirilebilir. Son olarak, gastronomik mirasın turizm amacıyla kullanımında yerel topluluğun katılımının ve kültürel özgünlüğün korunmasının temel bir ilke olarak benimsenmesi gerekmektedir. Gastronomik mirasın yalnızca ticari bir turizm ürününe dönüştürülmesi yerine, onu yaşatan toplulukların bilgi ve deneyimlerinin korunması ve görünür hâle getirilmesi sürdürülebilir bir gastronomi turizmi açısından önem taşımaktadır.

Çalışmanın temel sınırlılığı, önerilen modelin henüz ampirik olarak test edilmemiş olmasıdır. Bu nedenle gelecekteki araştırmalarda modelde önerilen ilişkilerin nicel veya nitel yöntemlerle sınanması önerilmektedir. Özellikle hikâye anlatıcılığının kültürel anlamlandırma üzerindeki etkisi, kültürel anlamlandırmanın duygusal bağ oluşturmadaki rolü ve deneyim değerinin destinasyon bağlılığına katkısı ampirik olarak araştırılabilir. Böylece bu çalışmada kavramsal düzeyde ortaya konulan modelin Kahramanmaraş gastronomi turizmi açısından geçerliliği test edilebilir.

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POTENTIAL ANTICANCER EFFECTS OF POMEGRANATE FRUIT EXTRACT ON NON-SMALL CELL LUNG CANCER CELLS: A COMPARISON WITH NON-MALIGNANT LUNG FIBROBLASTS

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Abstract
Lung cancer remains a major cause of cancer-related mortality, and therapeutic resistance and treatment-associated toxicity continue to limit clinical outcomes. Pomegranate (*Punica granatum* L.) fruit is rich in bioactive polyphenols, including punicalagins, ellagic acid derivatives, anthocyanins, and flavonoids, which have been associated with antioxidant, anti-inflammatory, and antiproliferative effects. This study aimed to evaluate the in vitro cytotoxic activity of pomegranate fruit extract against human lung cancer cells by the concentration- and time-dependent manner. The antiproliferative activity of pomegranate fruit extract was investigated in two human non-small-cell lung cancer cell lines, A549 and H1299, and a non-malignant human lung fibroblast cell line, MRC-5. Cells were exposed to five concentrations of the extract varying from 62.5, 125, 250, 500, to 1000 µg/mL for 24, 48 and 72 h. Cell metabolic activity was quantified using the MTT assay. Untreated cells served as the negative control, while cisplatin was included as a reference cytotoxic agent. Experiments were performed independently at least three times, with each concentration tested in triplicate. Concentration-response curves were generated by nonlinear regression, and half-maximal inhibitory concentration (IC_{50}) values were calculated. Selectivity indices were calculated as the ratio of the MRC-5 IC_{50} value to the corresponding cancer-cell IC_{50} value. Statistical significance was assessed using one-way analysis of variance followed by an appropriate multiple-comparison test. Pomegranate fruit extract reduced the metabolic viability of A549 and H1299 cells in a concentration- and time-dependent manner. The IC_{50} values for A549 cells were 248.60, 170.82, and 116.45 µg/mL after 24, 48, and 72 h, respectively, while the corresponding values for H1299 cells were 296.30, 209.10, and 152.80 µg/mL. MRC-5 cells exhibited IC_{50} values of 645.60, 446.80, and 280.14 µg/mL at the corresponding exposure periods. The selectivity indices for A549 cells were 2.60, 2.62, and 2.41, whereas those for H1299 cells were 2.18, 2.14, and 1.83 after 24, 48, and 72 h, respectively. A549 cells were therefore more sensitive to the extract than H1299 cells. Based on the prespecified criterion of SI ≥2, the extract demonstrated moderate selectivity toward A549 cells at all exposure periods and toward H1299 cells after 24 and 48 h. Consequently, the results demonstrate that pomegranate fruit extract possesses concentration-dependent in vitro activity against lung cancer cells and may show preferential toxicity toward malignant cells. Its polyphenol-rich phytochemical profile may contribute to the observed effect. Further studies involving phytochemical standardization, apoptosis and cell-cycle analyses, migration assays, molecular pathway evaluation are required to identify its therapeutic potential in non-small cell lung cancer.
Keywords: Non-small-cell lung cancer; *Punica granatum* L.; selective cytotoxicity; phytochemicals; MTT assay; natural anticancer agents

EFFECTS OF SEAWEED EXTRACTS ON YIELD, FRUIT QUALITY, AND STRESS TOLERANCE IN FRUIT CROPS

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Özet
Deniz yosunu ekstraktları, içerdikleri polisakkaritler, amino asitler, vitaminler, mineraller, fenolik bileşikler ve hormon benzeri biyoaktif maddeler nedeniyle tarımsal üretimde doğal biyostimülan olarak giderek daha fazla önem kazanmaktadır. Bu ekstraktlar; bitki büyüme ve gelişmesini teşvik etme, besin elementi alımını ve kullanım etkinliğini artırma, fotosentetik aktiviteyi destekleme ve çevresel streslere karşı bitki toleransını güçlendirme potansiyeline sahiptir. Bu derlemede, deniz yosunu ekstraktlarının meyve yetiştiriciliğinde kullanım olanakları ile verim, meyve kalitesi ve abiyotik stres toleransı üzerindeki etkileri güncel çalışmalar doğrultusunda değerlendirilmiştir. Çilek, üzüm ve diğer meyve türlerinde yürütülen çalışmalar, deniz yosunu ekstraktı uygulamalarının kök gelişimi, meyve tutumu ve sayısı, pazarlanabilir verim ve bazı meyve kalite özellikleri üzerinde olumlu etkiler oluşturabildiğini göstermektedir. Ayrıca bu uygulamaların fotosentez, besin elementi alımı ve taşınımı, antioksidan savunma sistemi, fenilpropanoid ve flavonoid metabolizması ile stres yanıtlarıyla ilişkili moleküler mekanizmaları düzenleyerek kuraklık, tuzluluk, düşük sıcaklık ve diğer çevresel stres koşullarına karşı toleransın artırılmasına katkı sağlayabileceği bildirilmektedir. Bununla birlikte, uygulamalardan elde edilen sonuçların deniz yosunu türü ve ekstraktın bileşimi, uygulama dozu ve zamanı, uygulama yöntemi, bitki türü ve çeşidi ile yetiştirme koşullarına bağlı olarak değişebildiği görülmektedir. Sonuç olarak, deniz yosunu ekstraktları meyve yetiştiriciliğinde bitki gelişimi ve verimliliğin desteklenmesi, meyve kalite özelliklerinin iyileştirilmesi ve abiyotik stres koşullarına karşı toleransın artırılması açısından önemli bir potansiyele sahiptir. Bu özellikleriyle deniz yosunu ekstraktlarının, çevresel streslerin giderek önem kazandığı günümüz üretim koşullarında, sürdürülebilir ve çevre dostu meyve yetiştiriciliğini destekleyen önemli biyostimülanlardan biri olduğu değerlendirilmektedir.
Anahtar Kelimeler: Deniz yosunu ekstraktı, biyostimülan, meyve yetiştiriciliği, verim, meyve kalitesi, abiyotik stres

ABSTRACT
Seaweed extracts are gaining increasing importance as natural biostimulants in agricultural production due to their rich composition of polysaccharides, amino acids, vitamins, minerals, phenolic compounds, and hormone-like bioactive substances. These extracts have the potential to promote plant growth and development, enhance nutrient uptake and use efficiency, support photosynthetic activity, and improve plant tolerance to environmental stresses. This review evaluates the potential uses of seaweed extracts in fruit production and their effects on yield, fruit quality, and abiotic stress tolerance based on current scientific literature. Studies conducted on strawberry, grapevine, and other fruit crops have demonstrated that seaweed extract applications can positively influence root development, fruit set and number, marketable yield, and various fruit quality attributes. Furthermore, these applications have been reported to contribute to enhanced tolerance to drought, salinity, low temperature, and other environmental stresses by modulating photosynthesis, nutrient uptake and translocation, antioxidant defense systems, phenylpropanoid and flavonoid metabolism, as well as molecular mechanisms associated with stress responses. However, the effects of these applications may vary depending on the seaweed species and extract composition, application rate and timing, application method, plant species and cultivar, and growing conditions. In conclusion, seaweed extracts have considerable potential to support plant growth and productivity, improve fruit quality, and enhance tolerance to abiotic stress conditions in fruit production. In this context, seaweed extracts can be regarded as important biostimulants for supporting sustainable and environmentally friendly fruit production under current growing conditions, where environmental stresses are becoming increasingly significant.
Keywords: seaweed extract, biostimulant, fruit production, yield, fruit quality, abiotic stress

INTRODUCTION

Seaweeds are widely distributed in marine and coastal ecosystems and are considered important natural resources due to their rich biochemical composition and diverse biologically active compounds. The major groups of seaweeds commercially utilized worldwide include red, brown, green, and blue-green algae. Among these groups, *Ascophyllum nodosum*, *Ecklonia maxima*, and *Laminaria* spp. from brown algae, *Kappaphycus alvarezii* from red algae, and *Ulva* spp. from green algae are particularly prominent as raw materials for the production of extracts used for agricultural purposes. In countries with extensive coastlines and abundant seaweed resources, such as Norway, Ireland, France, and the United States, efforts to economically utilize these natural resources have increased over time. The historical use of seaweeds as fertilizers has contributed to the development of research on their application in agricultural production and the fertilizer industry. Following the development of the commercial product known as "Maxicrop," derived from the brown seaweed *Ascophyllum nodosum*, in 1960, positive results were reported in studies conducted under both open-field and protected cultivation conditions (Craigie, 2011). Furthermore, seaweed extracts have been reported to enhance plant tolerance to various stress factors, promote root development (Matsiyak et al., 2011), and positively affect seedling growth and development (Kamaladhasan and Subramanian, 2009).

Seaweed is considered an effective organic fertilizer and is widely used to enhance crop productivity. Seaweed extracts used as organic fertilizers contain macronutrients such as N, P, and K, as well as micronutrients including Fe, Cu, Zn, Mo, and Mn. They are also known to contain plant hormones, particularly auxins and cytokinins, together with vitamins and amino acids (Shukla et al., 2019). In recent years, seaweed extracts have gained increasing attention in crop production because of their beneficial physiological effects, including improvements in crop quality and the promotion of plant growth and development (Kumar et al., 2012). This review aims to comprehensively evaluate the potential uses of seaweed extracts in fruit production and their effects on yield, fruit quality characteristics, and stress tolerance in light of current scientific evidence.

Composıtıon Of Seaweed Extracts And Theır Mechanısms Of Actıon In Plants

The chemical composition of seaweed extracts includes complex polysaccharides, fatty acids, vitamins, phytohormones, and mineral nutrients (Battacharyya et al., 2015). The biostimulant effects of seaweed extracts on plants are attributed not to the direct action of a single component but rather to complex physiological and molecular responses induced by the various bioactive compounds present in the extracts. Following the perception of these compounds by plants, several signal transduction pathways may be activated, leading to changes in metabolic processes associated with plant growth, development, and stress responses (Ali et al., 2021).

Studies investigating the effects of seaweed extracts at the molecular level have demonstrated that these applications can regulate the expression of various genes associated with plant growth and development. Applications of *Ascophyllum nodosum* extract have been reported to increase plant biomass, influence phenylpropanoid and flavonoid metabolism, and promote root and shoot development by enhancing nitrate uptake. Transcriptomic and metabolomic studies have further demonstrated that seaweed extracts can influence molecular processes associated with photosynthesis, endogenous hormone regulation, nutrient uptake and transport, and cell division. These findings indicate that seaweed extracts promote plant growth not only by supplying nutrients but also by regulating various physiological and molecular mechanisms (Sujeeth et al., 2022).

Borella et al. (2023) investigated the potential of brown seaweed extract to alleviate cold stress in tomato plants. They reported that the application of brown seaweed extract to tomato plants grown under low-temperature conditions contributed to the maintenance of stomatal conductance and photosynthetic rate, consequently resulting in positive effects on yield. In addition to maintaining photosynthetic activity under low-temperature conditions, seaweed extracts were found to enhance plant tolerance to cold stress through the regulation of genes involved in stress responses.

Use Of Seaweed Extracts In Fruıt Productıon

Studies investigating the use of seaweed extracts in fruit production indicate that these applications may particularly influence yield-related components such as root development, fruit set, fruit number, and

total yield. However, the responses obtained may vary depending on the seaweed species used, application concentration and method, plant species and cultivar, and growing conditions.

Mattner et al. (2018) investigated the effects of a commercial seaweed extract (Seasol®), derived from *Durvillaea potatorum* and *Ascophyllum nodosum*, on root development, nursery plant production, and fruit yield in strawberry. In three separate field trials conducted in Victoria, Australia, between 2014 and 2016, the seaweed extract was applied monthly at a rate of 10 L ha^{-1} to the strawberry cultivars 'Albion' and 'Fortuna'. During the nursery production stage, the application increased secondary root density by up to 22% and marketable nursery plant yield by 8–19%. During the fruit production period, seaweed extract application resulted in a 38% increase in root length density and an 8% increase in marketable fruit yield. Furthermore, a strong positive correlation ($r = 0.94$) was observed between root length density and marketable fruit yield. These findings suggest that the beneficial effect of seaweed extract on strawberry yield may be associated with the stimulation of root system development and demonstrate its potential use as a biostimulant in strawberry production.

Arioli et al. (2021) investigated the effects of soil application of a brown seaweed extract derived from *Durvillaea potatorum* and *Ascophyllum nodosum* on the yield of wine grape cultivars in Australia. The study was conducted between 2012 and 2017 across three different states, involving four grape cultivars and five locations. The results demonstrated that repeated soil applications of the seaweed extract increased wine grape yield by an average of 14.7% across different growing seasons and under extreme climatic conditions. In addition, a partial budget analysis showed that, although the economic effectiveness of the application varied among grape cultivars, it could potentially improve grower profitability. The findings obtained across different cultivars, locations, and growing seasons indicate that seaweed extracts have considerable potential as biostimulants for enhancing yield in viticulture.

Taskas et al. (2019) conducted a two-year study to evaluate the effects of seaweed extract on 'Merlot' grapevines. The effects of foliar seaweed extract applications on grapevine yield, chlorophyll content, berry number, and phenolic characteristics were investigated. The effectiveness of the seaweed extract was found to vary depending on application concentration and nitrogen fertilization conditions. In 2016, when no hail damage occurred, the most pronounced effects were obtained in vines treated with a 1% seaweed extract in combination with in-season nitrogen application. This treatment increased yield by 26%, berry number by 35%, and anthocyanin extractability from berry skins by 21%. Application at a lower concentration (0.2%) also increased berry number and anthocyanin extractability; however, it resulted in a reduction in total phenolic compounds and an increase in seed tannins. These findings suggest that, when applied at an appropriate concentration and under suitable nutritional conditions, seaweed extracts have potential as biostimulants for improving grapevine yield and certain quality attributes.

In a study conducted on the 'Alphonse Lavallée' grape cultivar, the effects of extracts obtained from brown seaweeds on yield, fruit quality, and selected physiological characteristics were investigated. Seaweed extracts were applied foliarly at four different developmental stages, and all treatments increased yield per vine by 28–47% compared with the control. In addition, the treatments improved cluster and berry characteristics and increased phenolic compound content and antioxidant activity. Seaweed extracts also had beneficial effects on physiological parameters such as photosynthetic activity and stomatal conductance. These findings indicate that extracts obtained from different brown seaweed species may be considered sustainable biostimulant applications for improving yield and quality characteristics in grape production (Doğan and Yazar, 2025).

Effects Of Seaweed Extracts On Abıotıc Stress Tolerance

In fruit production, abiotic stress factors such as drought, salinity, high and low temperatures are among the major environmental constraints limiting plant growth, photosynthetic activity, flowering, fruit set, yield, and fruit quality. The increasing frequency of extreme temperature events and water limitations associated with climate change has further emphasized the importance of sustainable practices capable of enhancing stress tolerance in fruit crops. In this context, seaweed extracts have emerged as important biostimulants that can support the physiological and biochemical defense mechanisms of plants against environmental stress conditions.

Shukla et al. (2019) reported that seaweed extracts promote plant growth, enhance nutrient-use efficiency, and improve plant tolerance to both abiotic and biotic stresses through their bioactive constituents. These beneficial effects have been associated with physiological, biochemical, and molecular mechanisms, indicating that seaweed extracts have considerable potential as biostimulants in sustainable crop production.

The beneficial effects of seaweed extracts against low-temperature stress have also been demonstrated experimentally. Borella et al. (2023) reported that the application of brown seaweed extract to tomato plants exposed to low-temperature stress increased stomatal conductance and net photosynthetic rate.

Seaweed extracts have also been reported to mitigate the adverse effects of environmental stresses such as drought, salinity, high temperature, and freezing. These applications may regulate physiological and metabolic changes occurring in plants under stress conditions and promote the activation of defense-related genes and metabolic pathways. Furthermore, extracts obtained from seaweeds such as *A. nodosum* and *Sargassum* spp. have been shown to enhance plant tolerance under drought and salinity conditions (Ali et al., 2021).

Conclusıons And Recommendatıons

Nevertheless, the responses obtained from seaweed extract applications may vary depending on the seaweed species and characteristics of the extract, application rate and timing, application method, plant species and cultivar, and growing conditions. Therefore, it is necessary to determine appropriate application rates and periods for individual fruit species, conduct long-term studies under different ecological conditions, and evaluate the economic feasibility of these applications. In conclusion, with the development of appropriate application strategies, seaweed extracts may represent an important biostimulant alternative for increasing yield and quality, mitigating the adverse effects of environmental stresses, and supporting sustainable production in fruit crops.

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CURRENT APPROACHES TO ADVANCING HARVEST TIME IN APRICOT

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Özet
Kayısı (*Prunus armeniaca* L.), dünya genelinde ekonomik öneme sahip sert çekirdekli meyve türlerinden biri olup, Türkiye küresel kayısı üretiminde önemli bir konuma sahiptir. Özellikle sofralık kayısı yetiştiriciliğinde hasat zamanının erkene alınması, ürünün pazara arzın sınırlı olduğu dönemde sunulmasına olanak sağlaması nedeniyle önemli bir yetiştiricilik hedefidir. Bu derlemede, kayısıda erkenciliği belirleyen temel faktörler ile hasat zamanının erkene alınmasına yönelik güncel yaklaşımlar; erkencilik, verim, meyve kalitesi ve don riski açısından değerlendirilmiştir. Kayısıda hasat zamanı; çeşidin genetik özellikleri, soğuklama ve sıcaklık gereksinimleri, tomurcuk uyanması ve çiçeklenme zamanı, meyve gelişim süresi, çeşit–anaç kombinasyonu ve yetiştirme bölgesinin ekolojik koşullarının etkileşimi sonucunda şekillenmektedir. Yapılan çalışmalar, uygun çeşit ve anaç seçiminin erkencilik açısından önemli olduğunu, dinlenmenin kontrollü olarak kırılmasına yönelik uygulamaların tomurcuk uyanması ve çiçeklenmeyi teşvik ederek hasat zamanını erkene alabildiğini göstermektedir. Ayrıca plastik örtü altında yetiştiricilik gibi yetiştirme ortamını değiştirmeye yönelik uygulamalarla da hasatta belirli düzeyde erkencilik sağlanabilmektedir. Bununla birlikte, erkenciliği teşvik eden uygulamaların etkinliği çeşit ve ekolojik koşullara bağlı olarak değişebilmekte; tomurcuk uyanması ve çiçeklenmenin erkene alınması özellikle ilkbahar geç donlarının görüldüğü bölgelerde don riskini artırabilmektedir. Sonuç olarak, kayısıda erkenci üretimin sürdürülebilir ve ekonomik olarak uygulanabilir hale getirilmesi için çeşit–anaç kombinasyonu, dinlenme yönetimi ve yetiştirme ortamına yönelik uygulamaların bölgesel ekolojik koşullar, don riski, verim ve meyve kalitesi ile birlikte değerlendirilmesi önem taşımaktadır.
Anahtar Kelimeler: kayısı, erkencilik, hasat zamanı, çeşit–anaç, dinlenmenin kırılması, örtü altı yetiştiricilik

Abstract
Apricot (*Prunus armeniaca* L.) is an economically important stone fruit species cultivated worldwide, and Türkiye holds a prominent position in global apricot production. Particularly in fresh-market apricot production, advancing harvest time is an important cultivation objective, as it enables fruit to enter the market during periods of limited supply. This review evaluates the major factors determining earliness in apricot and current approaches to advancing harvest time in terms of earliness, yield, fruit quality, and frost risk. Harvest time in apricot is determined by the interaction of several factors, including cultivar genetics, chilling and heat requirements, bud break and flowering time, fruit development duration, cultivar–rootstock combinations, and the ecological conditions of the growing region. Available studies indicate that appropriate cultivar and rootstock selection plays an important role in achieving earliness, while controlled dormancy-breaking treatments can advance harvest time by promoting bud break and flowering. In addition, modification of the growing environment through practices such as cultivation under plastic cover can provide a certain degree of earliness. However, the effectiveness of earliness-promoting practices may vary depending on cultivar and ecological conditions, while advancing bud break and flowering may increase the risk of frost damage, particularly in regions prone to late spring frosts. In conclusion, cultivar–rootstock combinations, dormancy management, and practices aimed at modifying the growing environment should be evaluated together with regional ecological conditions, frost risk, yield, and fruit quality to achieve sustainable and economically feasible early apricot production.

Keywords: apricot, earliness, harvest time, cultivar–rootstock, dormancy breaking, protected cultivation

INTRODUCTION

Apricot (*Prunus armeniaca* L.) is one of the economically important stone fruit species widely cultivated worldwide. Global apricot production reached approximately 4.60 million tonnes in 2024, while Türkiye produced 1,269,000 tonnes in the same year. Accordingly, Türkiye accounted for approximately 27.6% of total global apricot production, highlighting its prominent position in the global apricot industry. The diverse ecological conditions of Türkiye enable apricot cultivation across various regions, while its high production volume further underscores the country's importance in the global apricot sector (FAO, 2026).

Although apricot production in Türkiye is carried out across different ecological regions, production is concentrated in certain provinces. According to TÜİK data for 2024, Malatya ranked first in apricot production, followed by Mersin and Elazığ, while Hatay, Kahramanmaraş, Isparta, Antalya, and Iğdır were among the other major producing provinces. While Malatya stands out for its traditional production structure and extensive cultivation areas, Mersin is one of the country's major apricot production centers owing to the favorable growing conditions provided by the Mediterranean ecology (TÜİK, 2026). However, substantial changes occurred in the geographical distribution of production in 2025. According to TÜİK data for 2025, total apricot production in Türkiye amounted to 331,000 tonnes, with Mersin ranking first with a production of 141,142 tonnes and a share of 42.6%. Mersin was followed by Hatay (57,403 tonnes; 17.3%), Iğdır (51,085 tonnes; 15.4%), Antalya (26,148 tonnes; 7.9%), and Adana (9,362 tonnes; 2.8%) (TÜİK, 2026). The decline in Malatya's share to 0.8% in 2025, despite ranking first in production in the previous year, was largely associated with severe agricultural frost events during the production season (TÜİK, 2026). This situation highlights the importance of cultivation strategies involving cultivar selection adapted to ecological conditions, diversification of the production period, and management of phenological development in apricot cultivation.

In this context, earliness is an important trait that can increase the economic value of production, particularly in fresh-market apricot cultivation. Advancing the harvest date enables fruit to enter the market during periods of limited supply, thereby providing growers with a significant marketing advantage. The Mediterranean Region of Türkiye has considerable potential for early fresh-market apricot production owing to its mild winters and the early rise in temperatures during spring. In particular, the Mut district of Mersin is well known for very early apricot production, where the first harvests can be carried out during the first weeks of May (Asma et al., 2016). Studies conducted under the ecological conditions of Mersin have revealed significant differences among cultivars in terms of ripening time, and cultivars such as ‘Ninfa’, ‘Priana’, and ‘Precoce de Tyrinthe’ have been reported to possess considerable potential for early production (Pınar et al., 2010). Therefore, Mersin, and particularly the Mut district, represents an important production area for evaluating cultivars and cultivation practices aimed at achieving earliness in apricot production.

Earliness in apricot is not determined solely by the genetic characteristics of the cultivar but results from interactions among ecological conditions, chilling and heat requirements, cultivar–rootstock combinations, completion of dormancy, bud break and flowering time, and various cultural and chemical practices. Therefore, approaches aimed at advancing harvest time should be evaluated not only in terms of the earliness they provide but also with regard to their potential effects on yield, fruit quality, and particularly the risk of late spring frosts. This review aims to identify the major factors determining earliness in apricot; to examine current approaches for advancing harvest time, particularly cultivar and rootstock selection, dormancy management, and cultural, physical, and chemical practices; and to evaluate these practices in terms of earliness, yield, fruit quality, and frost risk.

FACTORS DETERMINING EARLINESS IN APRICOT

Earliness in apricot is a complex trait resulting from the interaction between the genetic characteristics of the cultivar and environmental conditions. The timing of dormancy release, bud break, and flowering, as well as the duration of fruit development, plays an important role in determining harvest time. Therefore, the evaluation of earliness should consider not only flowering time but also the period from flowering to harvest. Indeed, substantial genetic variation in flowering and ripening times has been

reported among apricot cultivars, indicating that earliness is strongly associated with cultivar selection (Ruiz and Egea, 2008).

In temperate fruit species such as apricot, cultivar-specific chilling requirements must be fulfilled during winter to ensure normal bud development. Following the fulfillment of the chilling requirement, the resumption of bud growth and subsequent flowering depend on the accumulation of a certain amount of heat. Consequently, chilling and heat requirements are among the fundamental factors determining the adaptation of apricot cultivars to different ecological conditions and their phenological stages. Researchers have also demonstrated a significant relationship between chilling requirements and flowering time. These differences emphasize the importance of cultivar selection in terms of phenological development and earliness, particularly in regions characterized by mild winters (Ruiz et al., 2007).

Flowering time and harvest time in apricot may not always be directly related, and the period from flowering to fruit ripening can vary considerably among cultivars. Milatović et al. (2010) reported substantial differences among apricot cultivars in the period from flowering to ripening and indicated that differences in ripening time may be more pronounced than differences in flowering time. Similarly, the flowering and ripening periods of apricot cultivars may vary under different ecological conditions (Polat et al., 2013). These findings indicate that the evaluation of earliness in apricot should consider not only flowering time but also fruit development duration, the genetic characteristics of the cultivar, and the ecological conditions of the growing region.

APPROACHES TO ADVANCING HARVEST TIME IN APRICOT

Approaches to advancing harvest time in apricot include various strategies, such as appropriate cultivar and rootstock selection, treatments aimed at breaking dormancy, and modification of the growing environment. The effectiveness of these approaches may vary depending on the genetic characteristics of the cultivar, ecological conditions, and application method.

Cultivar and rootstock selection is one of the fundamental cultivation practices for achieving earliness in apricot. Son and Küden (2003), who investigated the performance of different fresh-market apricot cultivars grafted onto apricot seedling and GF-31 rootstocks under Mut-Mersin conditions, reported that ‘Priana’ was the earliest cultivar on both rootstocks. Furthermore, full bloom and fruit ripening occurred earlier in cultivars grafted onto apricot seedlings than in those grafted onto GF-31. The researchers indicated that apricot seedlings were a suitable rootstock for the Mut region in terms of earliness, yield, and fruit quality characteristics. These results demonstrate that, in regions where early production is targeted, not only cultivar selection but also the identification of appropriate cultivar–rootstock combinations is of considerable importance (Son and Küden, 2003).

Another approach to advancing harvest time involves promoting bud break through the management of winter dormancy. Son and Küden (2005) investigated the effects of hydrogen cyanamide (Dormex) and Promalin applications on bud break, flowering, and harvest time in ‘Tokaloğlu’ and ‘Karacabey’ apricot cultivars under Mut conditions. The treatments increased bud break and advanced flowering by 2–5 days compared with the control. Harvesting was also reported to occur 2–9 days earlier in chemically treated trees than in untreated control trees. In addition, the treatments increased fruit weight (Son and Küden, 2005). These findings suggest that controlled dormancy breaking may contribute to enhancing earliness in apricot under suitable ecological conditions.

In recent years, treatments that may serve as alternatives to hydrogen cyanamide have also been investigated. Farag and Shehata (2024) evaluated applications of 2% mineral oil, 2% low-biuret urea, 1.5% ammonium nitrate, and 2% potassium nitrate, applied either individually or in combination with mineral oil, in the ‘Canino’ apricot cultivar. In particular, the combination of 2% mineral oil + 2% potassium nitrate was reported to have beneficial effects on bud break. The researchers suggested that these treatments could be considered as potential alternatives to hydrogen cyanamide for breaking dormancy in apricot (Farag and Shehata, 2024).

Physical methods based on modifying the growing environment have also attracted attention as strategies for enhancing earliness in apricot. Under Mut conditions, covering ‘Precoce de Tyrinthe’ apricot trees with plastic resulted in harvest occurring 8 days earlier than in uncovered control trees grown under open-field conditions (Küden et al., 2002).

Similarly, a study conducted with the 'Mogador' apricot cultivar under Hatay conditions reported that cultivation under plastic cover advanced harvest by 12 days compared with open-field cultivation. However, fruit grown under cover had lower fruit weight and total soluble solids content than fruit grown in the open field, indicating that the effects of practices aimed at achieving earliness on fruit quality characteristics should also be taken into consideration (Çalışkan et al., 2019).

Overall, advancing harvest time in apricot cannot be achieved through a single practice; rather, it requires the integrated consideration of different approaches, including cultivar–rootstock combinations, dormancy management, and modification of the growing environment. Nevertheless, practices that advance bud break and flowering should be applied cautiously in regions prone to late spring frosts, as they may expose reproductive organs to low temperatures at an earlier developmental stage. Therefore, methods used to achieve earliness should be selected by considering the ecological characteristics of the region, frost risk, cultivar characteristics, fruit quality, and the economic feasibility of the practice.

CONCLUSIONS AND RECOMMENDATIONS

Earliness in apricot is an important production objective, particularly for fresh-market production, as it enables the marketing period to be advanced and fruit to be supplied when market availability is still limited. However, harvest time is determined by the combined effects of cultivar genetics, chilling and heat requirements, fruit development duration, cultivar–rootstock combinations, and the ecological conditions of the production region. Therefore, rather than evaluating earliness solely on the basis of early flowering, the entire phenological process from bud break to fruit ripening should be taken into consideration.

Available studies indicate that harvest time in apricot can be advanced to a certain extent through appropriate cultivar and rootstock selection, controlled dormancy-breaking treatments, and cultivation under plastic cover. However, the fact that the responses to these practices vary depending on cultivar and ecological conditions demonstrates the need to develop region-specific strategies for achieving earliness. Furthermore, because advancing bud break and flowering may increase exposure to late spring frosts, the benefits associated with earliness should be evaluated together with potential changes in yield and fruit quality.

Future studies should evaluate the effects of earliness-promoting practices not only in terms of harvest date but also by considering phenological development, frost risk, yield, fruit quality characteristics, and economic feasibility. In particular, determining the performance of different cultivar–rootstock combinations under varying ecological conditions, developing alternative dormancy-breaking treatments to hydrogen cyanamide, and optimizing protected cultivation systems according to cultivar characteristics are of considerable importance. Integrating these approaches with regional climatic conditions and production objectives may contribute to making early apricot production more sustainable and economically feasible.

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ACOUSTIC INTEGRITY VS. TROPICAL VENTILATION: ASSESSING BUILDING ENVELOPE PERFORMANCE FOR NOISE MITIGATION IN DAY SECONDARY SCHOOLS OF MINNA, NIGERIA.

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ABSTRACT
In the fast-expanding landscape of Minna, Niger State, the proximity of educational facilities to high-noise transmission has created a discord between acoustic comfort and the requirements for natural ventilation. This paper assesses the effectiveness of various building envelope components specifically wall density, window configurations, and roofing systems in reducing sound transmission within the tropical climate of Minna. Utilizing a mixed-methods approach, the study employs architectural case studies of three-day secondary schools, an observational checklist of envelope perforations, and survey questionnaires across different material assemblies (e.g., sandcrete blocks vs. corrugated iron sheets). Preliminary analysis suggests that while "open-window" policies are essential for thermal regulation, they result in an average noise ingress of 65–72dB(A), far exceeding NESREA standards. Furthermore, the prevalence of lightweight zinc roofing acts as a secondary noise generator during peak precipitation. The paper proposes an "Integrated Envelope Framework" that employs acoustic louvers and high-mass partitions to harmonize thermal and auditory requirements, providing a good model for school design in Northern Nigeria.
Keywords: Noise Mitigation, Building Envelope, Acoustic Comfort, Minna schools, Tropical Architecture.

INTRODUCTION
The rapidly urbanizing cityscape of Minna, the capital of Niger State, presents acute challenges to the design and performance of public educational infrastructure. As municipal traffic networks expand and commercial precincts encroachment upon institutional land, secondary schools are increasingly exposed to high-intensity environmental sound fields. In tropical climate zones like Northern Nigeria, architectural design relies heavily on natural ventilation to manage indoor thermal conditions. However, this necessity creates a fundamental structural conflict: building envelopes designed with high window-to-wall ratios for air movement allow unattenuated noise ingress.
The standard architectural model across public secondary schools in Minna features single-skin sandcrete block walls, uninsulated corrugated metal roofing, and unglazed or open-shutter window assemblies. While these envelope choices minimize initial capital expenditure and facilitate cross-ventilation, they offer virtually zero acoustic resistance against ambient urban noise. High sound pressure levels directly degrade speech intelligibility, disrupt working memory, and induce physiological fatigue in both students and teachers.
This paper evaluates how specific building envelope components influence internal sound transmission in Minna secondary schools. By synthesizing physical envelope audits with empirical sound measurements and user perceptions, the study addresses the core design trade-off between thermal regulation and acoustic isolation, culminating in an actionable "Integrated Envelope Framework" tailored for tropical public infrastructure.

LITERATURE REVIEW
Indoor Environmental Quality (IEQ) requires an acoustic climate where background sound pressure levels do not impede verbal communication.

The World Health Organization (2018) recommends that background noise in instructional spaces should not exceed 35 dB(A). In Nigeria, the National Environmental Standards and Regulations Enforcement Agency (NESREA) stipulate a maximum daytime ambient noise limit of 55 dB(A) for educational zones. Excessive background noise triggers cognitive overhead, impairing information processing, reading comprehension, and numerical reasoning in adolescents (Fretes & Palau, 2025; Caviola et al., 2021).

In naturally ventilated tropical environments, the building envelope must fulfill dual, often contradictory functions. Achieving acceptable indoor air velocities demands open apertures, yet every open window acts as an acoustic bypass (Intan et al., 2023). Research on naturally ventilated classroom typologies indicates that opening windows to meet thermal comfort thresholds can elevate indoor sound levels by up to 25 dB(A) relative to closed conditions (Kim et al., 2016; Van Reenen & du Plessis, 2022). Furthermore, building envelope mass plays a pivotal role: hollow sandcrete blocks commonly used in West African construction lack the sound transmission class (STC) rating necessary to attenuate low-frequency urban traffic noise (Atilade et al., 2024).

In sub-Saharan Africa, roof assemblies are rarely evaluated for acoustic performance. Public secondary school structures predominantly employ uninsulated, lightweight corrugated zinc or galvanized iron sheeting directly fixed to timber trusses without acoustic ceiling boards. During severe weather events, high-velocity rainfall striking these uninsulated metal sheets generates intense impact noise, raising indoor sound levels above 80 dB(A) and completely halting academic instruction (Sop Sop Maturin Désiré et al., 2022).

Thus, a better understanding of noise effects and how to mitigate environmental noise in schools is necessary without compromising on natural ventilation.

METHODOLOGY

This study employed a convergent parallel mixed-methods design across three public day secondary schools in Minna, selected to represent distinct envelope assemblies and locational noise exposures.

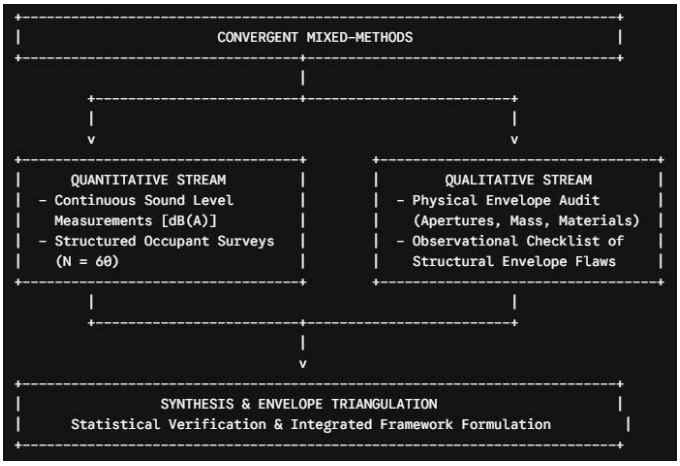


Figure 1. convergent parallel mixed-methods design

Data Collection Procedures

1. **Physical Envelope Audit:** A systematic observational checklist recorded envelope parameters across the three school sites, including wall material composition, hollow versus solid block fill, window-to-wall ratios (WWR), aperture closure mechanisms, and roof assembly details (truss depth, insulation presence, ceiling board installation).
2. **Acoustic Field Measurements:** Ambient sound pressure levels were recorded over three consecutive school days during peak instructional hours (08:00–14:00) using calibrated Class 2 sound level meters. Measurements captured both continuous equivalent sound levels and peak impact levels.
3. **Occupant Surveys:** Structured perception questionnaires were administered to a stratified sample of N = 60 respondents (n = 20 per school) to evaluate perceived sound disruption, speech clarity, and environmental satisfaction.

FINDINGS AND ANALYSIS

Envelope Performance and Ingress Sound Levels

The physical audit confirmed that all three schools rely on unassisted natural ventilation with high open-apertures. Sound level measurements revealed severe acoustic compliance failures across all sites.

Table 1. Sound level measurements

School Typology	Primary Envelope Material	Window Configuration	Mean Ingress Level Leq	NESREA Limit Exceedance
School 1 (Roadside Corridor)	225mm Hollow Sandcrete	Unshielded Open Metal Shutters	72 dB(A)	+17 dB(A)
School 2 (High-Density Urban)	150mm Hollow Sandcrete	Timber Louvers (Unsealed)	68 dB(A)	+13 dB(A)
School 3 (Aging Suburb)	Cracked/Deteriorated Blockwork	Damaged Frame Openings	65 dB(A)	+10 dB(A)

As shown in the data, natural cross-ventilation policies result in an average noise ingress of **65 to 72 dB(A)** across the schools. This ambient sound field significantly exceeds the NESREA statutory threshold of 55 dB(A) for educational spaces, severely compromising speech intelligibility.

Roof Assemblies as Secondary Noise Generators

Observational checklists and physical measurements identified lightweight zinc roofing as a major acoustic failure point. In 88% of surveyed classrooms, corrugated zinc sheets were installed without ceiling boards or acoustic insulation. During heavy precipitation events:

- Impact noise generated by rain on uninsulated metal sheeting raised internal sound levels to 78-84 dB(A).
- 95% of surveyed teachers reported needing to cease speaking entirely during rain bursts due to complete loss of speech intelligibility.

Occupant Perception Analysis

Survey data confirmed that envelope-mediated noise ingress strongly correlates with diminished occupant satisfaction and elevated classroom stress:

- **81.7%** of total respondents reported that ambient noise ingress directly interfered with instructional retention and cognitive focus.
- In **School 1**, where outdoor vehicular traffic combined with low envelope attenuation, a strong negative correlation was observed between exterior noise exposure and overall environmental satisfaction ($r_s = -0.618$, $p = .004$).

The Integrated Envelope Framework

To resolve the conflict between natural ventilation requirements and acoustic protection, this paper proposes the Integrated Envelope Framework (IEF**)** for tropical educational architecture in Northern Nigeria.

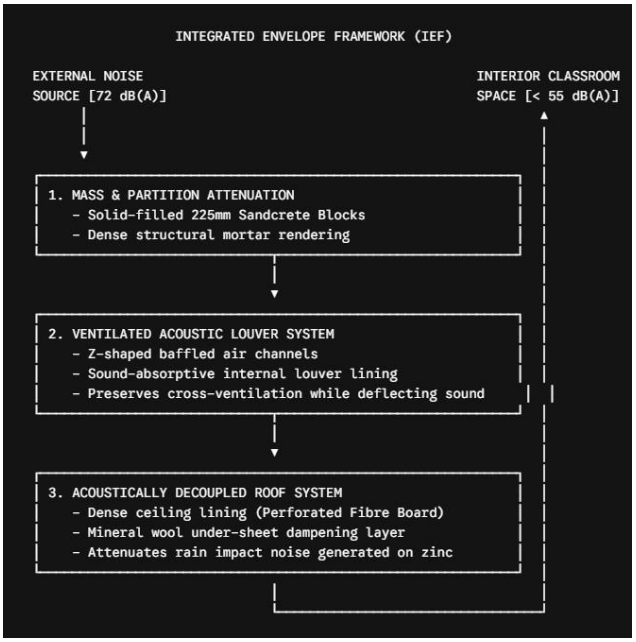


Figure 1. Integrated Envelope Framework (IEF)

Core Framework Components

1. **Baffled Acoustic Louvers:** Replacing open metal shutters with staggered, acoustic-lined Z-blade louvers allows airflow for thermal comfort while forcing sound waves through sound-absorbing pathways, reducing direct noise ingress by up to 12–15 dB(A).
2. **High-Mass Sandcrete Partitions:** Transitioning from hollow blockwork to solid-core sandcrete blocks (rendered with dense cement plaster) elevates the wall assembly's Sound Transmission Class (STC), insulating classrooms from external street noise and adjacent block interference.
3. **Decoupled Ceiling Sub-Assemblies:** Installing locally sourced, porous acoustic ceiling boards (e.g., compressed bagasse or mineral fiber) beneath corrugated metal roofs absorbs internal reverberation and dampens rain-impact sound transmission.

CONCLUSION

This study demonstrates that building envelope design in public secondary schools across Minna fails to provide sufficient acoustic protection, forcing a critical condition between thermal regulation and auditory comfort. Current open-window patterns yield noise ingress levels reaching 72 dB(A), while uninsulated zinc roofs exacerbate internal noise during rain events. Resolving this issue does not require expensive, energy-intensive mechanical HVAC systems. Implementing the proposed **Integrated Envelope Framework**—using acoustic louvers, solid block masonry, and insulated ceiling planes—enables secondary schools in Northern Nigeria to maintain passive natural ventilation while meeting statutory acoustic standards for optimal learning.

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NAVIGATING THE DIGITAL LANDSCAPE: THE INTERPLAY OF RELIGION AND TECHNOLOGY IN CONTEMPORARY SOCIETY

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ABSTRACT
Religion and technology are increasingly connected in contemporary society as digital tools reshape how people believe, worship, learn, and form communities (Campbell, 2013; Cheong et al., 2012). The following central research question guides this essay: How does the ongoing integration of digital technology influence religious practices, identities, and ethical responses within contemporary faith communities? The essay examines how technology influences religious practice and how religion guides ethical responses to technological change. Its objectives are to identify key areas of interaction, review relevant ideas on digital religion, apply documentary analysis as a method, and explain the social relevance of this relationship. The literature shows that digital media now supports online worship, religious education, interfaith dialogue, and virtual communities, while also challenging traditional authority, privacy, authenticity, and sacred experience. Using documentary analysis, the study interprets books, articles, documentaries, online sermons, religious websites, and digital platforms to understand patterns in religious communication and technological adaptation. The conceptual framework links mediatization, meaning-making, community formation, and ethics, suggesting that technology is not neutral but becomes meaningful through human and religious values. The expected outcome is a clearer understanding of how faith communities use technology to preserve identity, expand participation, and respond to modern social needs. The results indicate that technology can enhance religious access, especially for distant or marginalized believers. Still, it may also create distraction, misinformation, commercialization, and weakened face-to-face fellowship. The study's relevance lies in its ability to help religious leaders, educators, and policymakers use technology responsibly. In conclusion, religion and technology should be viewed as interacting forces that shape moral life, communication, and belonging. It is recommended that faith communities promote digital literacy, uphold ethical values, and balance online engagement with in-person community life.
Keywords: digital religion, technology, religious communication.

Introduction
In the modern era, the relationship between religion and technology has grown increasingly complex and significant (Hjarvard, 2011; Campbell, 2013). As digital innovations rapidly transform every aspect of society, religious beliefs and practices are also adapting in new and sometimes unexpected ways (Cheong et al., 2012). Technology not only shapes how faith is expressed and shared, but also influences the ethical frameworks and communal life of believers (Lundby, 2012). This essay explores the evolving interplay between religion and technology, highlighting the opportunities and challenges that emerge as faith communities navigate the digital landscape. By examining contemporary examples and theoretical perspectives, the discussion aims to illuminate how technology is both reshaping and being shaped by religious values in today's interconnected world (Helland, 2005).

Literature Review
The intersection of religion and technology has received considerable scholarly attention in recent decades (Campbell, 2013; Helland, 2005; Cheong et al., 2012). Campbell (2013) introduced the concept of "digital religion," highlighting how new media platforms facilitate both continuity and change in religious identity and community. Researchers such as Helland (2005) distinguish between "religion online," in which traditional institutions use the internet for outreach, and "online religion," in which digital spaces become actual contexts for religious practice and meaning-making. Studies emphasize the role of digital media in enabling virtual worship, globalized religious education, and transnational faith communities (Cheong et al., 2012).
However, the literature also identifies key challenges. Lundby (2012) and Hutchings (2017) point to the erosion of religious authority and authenticity in decentralized digital environments.

Issues of privacy, surveillance, and data ethics are increasingly relevant as religious groups use social media and proprietary platforms. Research by O'Leary (2012) and Wagner (2019) notes the commercialization of online spirituality and the risk of echo chambers that reinforce ideological divisions. In addition to these concerns, some scholars express skepticism about the supposed democratizing effects of digital religion, arguing that online engagement may reinforce existing inequalities or marginalize certain traditions and voices. Others critique the optimistic view of digital participation, suggesting that technology can lead to a superficial or fragmented religious experience, and question whether online spaces can genuinely replicate the depth of in-person spiritual encounters. These dissenting perspectives highlight the importance of approaching digital religion critically and recognizing the diverse range of scholarly opinions in the field.

Conceptual frameworks for understanding digital religion often draw from mediatization theory, which examines how media technologies shape and are shaped by religious meanings and practices (Hjarvard, 2011). Scholars also analyze how digital tools support ethical deliberation, community formation, and negotiation of sacred/profane boundaries in online contexts.

The literature demonstrates that technology is embedded in the everyday life of faith communities, offering both opportunities for innovation and pitfalls that require careful ethical consideration. Ongoing research is needed to address emerging issues such as the use of artificial intelligence in spiritual guidance, algorithmic bias in religious content, and the digital divide that affects access to online faith resources.

Methodology

This study employs a documentary analysis approach, relying solely on the examination of existing written and audiovisual materials (Campbell, 2013; Hjarvard, 2011). No surveys or interviews are conducted; instead, the analysis focuses exclusively on books, scholarly articles, documentaries, online sermons, religious websites, and digital platforms. To ensure rigour and transparency, sources were selected based on their scholarly credibility, relevance to the interplay of religion and technology, publication within the past two decades, and diversity in denominational or cultural perspectives (Cheong et al., 2012; Wagner, 2019). The analytical process consisted of identifying recurring themes, comparing interpretations across sources, and mapping patterns in religious communication and technological adaptation (Lundby, 2012; Hutchings, 2017). By systematically analyzing these secondary sources, the research identifies patterns in religious communication and technological adaptation. However, this method also entails certain limitations. Documentary analysis cannot directly capture lived experiences, personal motivations, or the nuanced ways individuals and communities engage with emerging technologies in real time. As such, the study may not fully reflect recent trends, rapidly evolving practices, or the subjective meanings that participants themselves attribute to digital religion. Recognizing these constraints demonstrates a critical awareness of the methodological boundaries and underscores the importance of complementing documentary analysis with empirical research in future investigations. The conceptual framework links mediatization, meaning-making, community formation, and ethics, suggesting that technology is not neutral but becomes meaningful through human and religious values (Hjarvard, 2011). The expected outcome is a clearer understanding of how faith communities use technology to preserve identity, expand participation, and respond to modern social needs.

Conceptual Framework

This study's conceptual framework draws on four interconnected themes to understand the interplay between religion and technology (Hjarvard, 2011). First, mediatization theory (Hjarvard, 2011) explains how digital technologies do not merely transmit religious messages; they also reshape the structure, authority, and expression of religious life, actively transforming religious meanings and practices. Second, the concept of meaning-making shows how religious communities use digital platforms to construct, negotiate, and share their beliefs, with online spaces becoming arenas for the reinterpretation of doctrine, ritual, and identity (Campbell, 2013). Third, community formation is explored by considering how technology enables faith communities to exist and flourish beyond physical boundaries, supporting virtual worship, online fellowship, and transnational networks (Cheong et al., 2012).

Finally, the theme of ethics investigates how religious values shape engagement with technology, particularly around digital privacy, authenticity, authority, and the negotiation of sacred and profane boundaries (Lundby, 2012; Wagner, 2019). By integrating these themes, the framework highlights that technology is not a neutral tool but is continually shaped by—and shaping—religious values, practices, and social relationships. This approach provides a nuanced lens for analyzing the adaptive and sometimes contested relationship between faith and digital innovation.

Results and Findings

The analysis reveals that technology has become an integral part of contemporary religious life, offering both significant opportunities and notable challenges (Bingaman, 2023; Lohlker & Wahid, 2026). One of the most prominent findings is that digital platforms have expanded access to religious content, making worship, education, and community engagement more inclusive, particularly for individuals who are geographically distant or otherwise marginalized (Cheong et al., 2012; Pew Research Center, 2023). For instance, the pandemic-era growth of virtual worship initiatives such as Life. Church's Church Online platform enabled thousands to attend weekly services remotely. At the same time, similar initiatives were launched by mosques and temples, including the digital streaming of Friday prayers or Buddhist chanting sessions (Churches, mosques and temples livestream religious services, 2020). Religious education has also adapted, with institutions such as the Jewish Theological Seminary offering online courses and webinars to maintain learning during periods of restricted in-person gatherings (Webinars, 2020). Faith-based discussion forums such as Christian Chat, Ummah.com, and TempleTalk have provided interactive spaces for believers to exchange perspectives, support one another, and deepen their religious identity, further illustrating how technology enables participation in religious life beyond traditional physical boundaries (Lohlker & Wahid, 2026).

However, the findings also show that the digitalization of religion is not without drawbacks. Increased reliance on technology may lead to weakened face-to-face fellowship, greater exposure to misinformation or commercialized spirituality, and challenges regarding the authenticity and authority of religious leaders and teachings. (Bingaman, 2023) Issues such as data privacy, surveillance, and the creation of ideological echo chambers are increasingly relevant as religious communities adopt social media and proprietary digital platforms. (Lorenz-Spreen et al., 2023)

Despite these challenges, many faith communities have demonstrated adaptability by developing new forms of ritual, fostering virtual fellowship, and using technology to promote social justice and interfaith dialogue. The study finds that religious leaders, educators, and policymakers play a crucial role in guiding ethical digital engagement, promoting digital literacy, and ensuring that online participation complements rather than replaces meaningful physical community life. The results underscore the dynamic and reciprocal relationship between religion and technology, suggesting that faith communities will continue to shape and be shaped by digital innovation.

Discussion

These findings reveal several implications for the ongoing interplay between religion and technology. First, the expansion of digital platforms has not only democratized access to religious content but has also challenged traditional religious hierarchies and structures. Individuals who were once peripheral to religious life due to geography, disability, or social status now find new avenues for participation and expression. This inclusivity has led to greater diversity in religious voices and practices, allowing for the emergence of previously marginalized interpretations and communities. (AlMazaedh et al., 2026) However, this same democratization can challenge established authority, leading to debates over authenticity, orthodoxy, and the legitimacy of online religious leaders or influencers. Notably, there is considerable variation in how different religious traditions adapt to digital environments, rooted in both theological and cultural factors. For example, many Christian denominations, especially Protestant and Evangelical churches, have readily incorporated livestreamed services, online communities, and digital outreach to fulfill their evangelistic missions and promote accessibility. By contrast, certain Orthodox Jewish communities carefully regulate or limit digital engagement due to religious laws, such as the prohibition on electronics on the Sabbath, and concerns about preserving tradition and authority. Islamic scholars and institutions may provide religious rulings, or fatwas, regarding the permissibility of social

media use, often weighing the benefits of global connection and religious education against risks such as exposure to inappropriate content and loss of religious discipline.

Buddhist practitioners often use digital apps for meditation, textual study, and teaching, drawing on an emphasis on adaptability and individual practice, yet still negotiating the effects of online interactions on community dynamics and authenticity. These differing approaches are influenced by doctrinal priorities, interpretations of sacred texts, attitudes toward modernity, leadership structures, and the relative openness of traditions to innovation. In traditions where spiritual authority is more centralized and ritual purity is emphasized, as in some Orthodox or hierarchical contexts, digital adaptation tends to proceed more cautiously, with established leaders often guiding or setting boundaries for online participation.

In contrast, more decentralized or congregational communities may embrace technological experimentation, seeing it as a means to foster participation and inclusivity. These examples reflect the complexity and diversity of religious responses to technology, highlighting how cultural context, religious law, theological orientation, and community structure collectively shape the trajectory of digital adaptation. (Gelfgren, 2012)

A second important theme is the transformation of religious rituals and practices. The migration of worship, prayer, and study sessions to digital platforms has required faith communities to negotiate what constitutes a valid or meaningful religious experience. While some traditions have embraced livestreamed services and virtual sacraments, others remain cautious, questioning whether digital participation can ever truly replicate the sacredness of in-person gatherings. (Dein & Watts, 2023) This tension highlights the ongoing negotiation of boundaries between the sacred and the profane in the digital age, with different communities arriving at diverse conclusions based on their theological, cultural, and historical contexts.

The rise of digital religion has facilitated new forms of community formation. Online groups, forums, and social media networks allow believers to form connections that transcend national, denominational, or linguistic barriers. These virtual communities can provide essential support, foster interfaith dialogue, and mobilize collective action for social justice causes. (Many Americans Like Online Religious Services but In-Person Still Preferred, 2023) On the other hand, they can also contribute to the formation of echo chambers, where like-minded individuals reinforce each other's beliefs while excluding dissenting voices. (Nazarov et al., 2025) The challenge for faith communities lies in leveraging technology's connective power while remaining vigilant against fragmentation and polarization.

The ethical dimension of digital religion is another critical area for discussion. Issues of privacy, surveillance, and data security are particularly salient as religious communities rely more heavily on proprietary platforms and digital communication tools. The digital traces left by participants in online religious activities can expose them to risks, especially in contexts where religious affiliation may lead to discrimination or persecution. (Criado et al., 2020) Faith leaders and organizations must therefore develop robust digital literacy programs and ethical guidelines to protect their members and ensure responsible engagement with technology.

Commercialization and commodification also feature prominently in the digital religious landscape. The proliferation of religious apps, online donation platforms, and monetized content raises questions about the boundaries between spiritual practice and market forces. (Use of apps and websites in religious life, 2023) While technology can provide valuable resources and enable financial sustainability, there is a risk that commercial imperatives may overshadow spiritual values, leading to the dilution or distortion of religious teachings.

Despite these challenges, the adaptability and resilience of faith communities are evident. Many have creatively reimagined rituals, developed hybrid models of worship, and used technology to promote inclusion, education, and activism. Religious leaders, educators, and policymakers play a pivotal role in mediating the relationship between faith and technology, setting standards for ethical engagement, and advocating for policies that protect the vulnerable while encouraging innovation.

Conclusion

The interplay between religion and technology is marked by both continuity and change (Campbell, 2013; Cheong et al., 2012; Lundby, 2012). While digital tools have transformed how faith is practiced, communicated, and experienced, the core concerns of meaning, community, and ethics remain central

(Hjarvard, 2011; Hutchings, 2017). This analysis makes a unique contribution by applying a critical lens to synthesize current scholarship, highlighting not only the opportunities and challenges posed by digital religion but also the nuanced ways in which faith communities actively negotiate their identities and ethical imperatives in digital spaces (Gelfgren, 2012; Dein & Watts, 2023). By mapping patterns of adaptation and resistance across different traditions, this study provides a clearer framework for understanding the mutual shaping of religious life and technology (AlMazaedh et al., 2026; Bingaman, 2023). The future of digital religion will depend on faith communities' capacity to harness technology's benefits while critically assessing its risks, ensuring that technological innovation serves the higher aims of spiritual growth, communal solidarity, and ethical responsibility (Lundby, 2012; Wagner, 2019; Pew Research Center, 2023).

Recommendation

To advance the field, specific future research is needed (AlMazaedh et al., 2026; Bingaman, 2023). Empirical studies could investigate how AI-driven tools are integrated into religious education and their influence on theological interpretation across different traditions (Mahyoub, 2026; Plate & Hutson, 2025). Longitudinal research might explore the effects of sustained digital participation on religious identity formation, especially among younger generations (Banks, 2025). Comparative studies could examine digital inclusion and exclusion in marginalized or minority faith communities, identifying barriers to access and participation (Cheong et al., 2012; Pew Research Center, 2023). Qualitative research focusing on firsthand experiences of virtual religious rituals would shed light on perceptions of authenticity and sacredness in digital spaces (Dein & Watts, 2023). Additionally, researchers should address the implications of algorithmic bias in the dissemination of religious content and explore strategies for mitigating misinformation within online faith communities (Nazarov et al., 2025; Criado et al., 2020). Such targeted investigations would provide concrete insights and help guide both theory and practice as religion continues to evolve in a rapidly changing digital landscape.

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PROTECTING FISH RESOURCES FROM MARINE POLLUTION: CHALLENGES AND SUSTAINABLE SOLUTIONS

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Abstract
Marine pollution is one of the greatest threats to fish resources and the health of aquatic ecosystems. Plastic waste, chemical contaminants, untreated wastewater, and other pollutants degrade water quality, destroy habitats, and reduce fish populations. Protecting this valuable natural resource requires integrated management strategies, including reducing plastic inputs, improving waste collection and recycling, strengthening wastewater treatment, and enforcing environmental regulations. In addition, raising public awareness and promoting sustainable fishing practices are essential to preserving marine biodiversity and ensuring the long-term sustainability of fisheries. These combined efforts are crucial for safeguarding fish resources and maintaining healthy marine ecosystems for future generations.
Keywords: Marine pollution; Fish resources; Sustainable fisheries; Plastic waste; Marine conservation; Environmental protection; Coastal ecosystems.

SPATIAL AND GENDERED EXPENDITURE DYNAMICS: *WELFARE DIVERGENCE IN WEST JAVA*

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Abstract
This study examines spatial disparities in household expenditure across cities and regencies in West Java, Indonesia, to evaluate regional economic welfare. Household expenditure is utilized as a robust welfare proxy because it captures purchasing power and living standards more comprehensively than income metrics. Using data from 27 cities and regencies in West Java covering the period 2019–2024 (162 observations), descriptive statistical analysis assesses average expenditure, variability, and distribution by gender and regional type. The results reveal deep-seated welfare disparities between urban and rural classifications. Average expenditure is higher in cities for both men and women, with the urban-rural gap being significantly wider among female cohorts. Cities display higher spending, indicating pronounced internal inequalities in purchasing power. This research enriches the regional economics literature by validating household expenditure as an empirical indicator of territorial well-being. These empirical insights offer an objective foundation to improve fiscal planning, guide targeted social assistance programs, and optimize resource allocation to mitigate regional welfare imbalances.
Keywords: economic welfare, household expenditure, spatial disparities, gender-based analysis.

AGENTIC ARTIFICIAL INTELLIGENCE FOR AUTONOMOUS ENTERPRISE WORKFLOW AUTOMATION TRANSFORMING BUSINESS OPERATIONS THROUGH INTELLIGENT DECISION-MAKING

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ABSTRACT
The rapid evolution of Artificial Intelligence (AI) has introduced Agentic AI as a transformative paradigm capable of autonomously planning, reasoning, and executing complex business workflows with minimal human intervention. Unlike conventional AI systems that rely primarily on predefined prompts, Agentic AI integrates planning, memory, reasoning, and adaptive learning to complete multi-step organizational tasks. This study investigates the impact of Agentic AI on enterprise workflow automation across finance, healthcare, manufacturing, and customer service industries. The research examines how intelligent agents improve operational efficiency by reducing repetitive manual tasks, enhancing decision accuracy, and enabling continuous process optimization. A conceptual framework integrating Large Language Models (LLMs), Retrieval-Augmented Generation (RAG), enterprise knowledge bases, and multi-agent collaboration is proposed to demonstrate autonomous workflow execution. The paper further explores implementation challenges including governance, security, ethical considerations, regulatory compliance, and human oversight. Comparative analysis indicates that organizations adopting Agentic AI experience improved productivity, faster decision cycles, and enhanced customer satisfaction while significantly lowering operational costs. Furthermore, the study highlights the growing role of autonomous AI ecosystems in enabling digital transformation and business resilience within increasingly competitive markets. The findings suggest that Agentic AI will become a foundational technology for next-generation intelligent enterprises by enabling scalable, adaptive, and context-aware business operations.

Keywords: Agentic AI, Autonomous Systems, Enterprise Automation, Intelligent Agents, Business Process Automation, Large Language Models, Digital Transformation

INDIGENOUS PLAY TRADITIONS AS CULTURAL RESOURCES FOR EARLY CHILDHOOD ENVIRONMENTS IN NIGERIA

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ABSTRACT
The increasing influence of globalization and Western-oriented models of early childhood education has contributed to the gradual decline of indigenous play traditions across many African societies. In Nigeria, traditional games, storytelling, folk songs, locally made toys, and communal childhood activities have historically served as important mechanisms for cultural transmission, socialization, identity formation, and holistic child development. This paper presents a comprehensive literature review on indigenous play traditions as cultural resources for early childhood environments in Nigeria. The review synthesizes existing scholarly literature on indigenous knowledge systems, childhood play, cultural practices, environmental learning, and child development, with particular emphasis on the Yoruba, Igbo, Hausa, Nupe, and Gwari cultural groups. A thematic and comparative review approach is adopted to examine recurring indigenous play practices, cultural values, and their implications for the planning and design of contemporary early childhood environments. The reviewed literature indicates that indigenous play traditions promote cognitive, physical, social, emotional, and moral development while strengthening cultural identity, creativity, cooperation, problem-solving skills, and intergenerational knowledge transfer. The review further reveals that indigenous play activities provide culturally meaningful learning experiences that are often overlooked in contemporary childcare and educational settings. Despite growing recognition of culturally responsive learning environments, the integration of indigenous play traditions into the design of daycare centres and children's play spaces in Nigeria remains limited. The review concludes that indigenous play traditions represent valuable cultural resources capable of enriching early childhood environments while supporting cultural preservation and sustainable childhood development. It recommends greater integration of indigenous cultural knowledge into the planning, design, and management of early childhood facilities and identifies areas for future empirical research on culturally responsive play environments in Nigeria.
Keywords*:* Indigenous play traditions; early childhood environments; architectural design; cultural resources; spatial configuration; Nigeria

1. INTRODUCTION
Across many African societies, children's play has traditionally unfolded within the dense fabric of communal life rather than inside specialised, purpose-built facilities. Games, oral narratives, songs, and craft activities passed between generations under the guidance of compounds, courtyards, and village squares have functioned simultaneously as recreation and as a primary vehicle of cultural transmission (Rogoff, 2003). In Nigeria, as in much of the Global Majority, the widening influence of globalization and the importation of Western-oriented models of early childhood education have progressively displaced these indigenous play traditions, replacing communally embedded activity with standardised equipment and imported pedagogical scripts that carry little connection to the cultural lives of the children who use them (Ogunyemi & Henning, 2020).
Play is now widely recognised across developmental psychology and education as a central mechanism of cognitive, social, emotional, physical, and moral development in early childhood. Yet the body of research documenting these benefits has been developed largely within Western, industrialised contexts, and its findings and design recommendations do not transfer in any straightforward way to the culturally diverse realities of children in West Africa.

Nigeria's indigenous play traditions, expressed through the games, oral literature, music, and craft-based activities of its major ethnic groups, constitute a cultural resource of considerable developmental and pedagogical value that remains largely unexploited in the design and management of contemporary early childhood facilities.

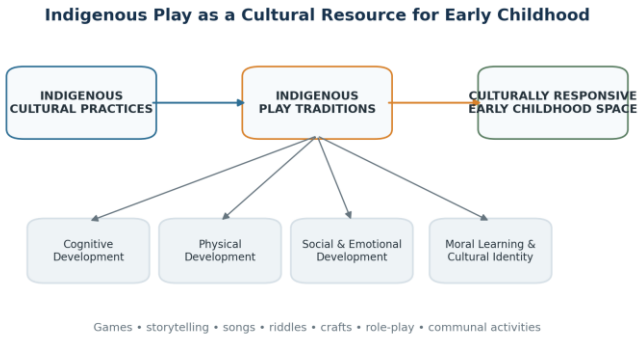


Figure 1. Conceptual relationship between indigenous play traditions, child development, cultural transmission and early childhood environments.

Source: Author's research work (2026)

This paper presents a thematic and comparative literature review of indigenous play traditions as cultural resources for early childhood environments in Nigeria, with particular emphasis on the Yoruba, Igbo, Hausa, Nupe, and Gwari cultural groups. The review synthesises scholarship on indigenous knowledge systems, childhood play, cultural practice, environmental learning, and child development to establish, first, the developmental and cultural significance of indigenous play traditions, and second, the extent to which these traditions have been integrated into the design of contemporary childcare and early learning environments in Nigeria. The remainder of the paper is organised as follows: Section 2 reviews the theoretical and empirical literature on play as a developmental and cultural practice and surveys indigenous play traditions across the five focal cultural groups; Section 3 describes the review methodology; Section 4 presents the thematic and comparative findings; Section 5 discusses their implications for the planning and design of early childhood environments; and Section 6 concludes with recommendations for practice and future research.

2. LITERATURE REVIEW

2.1 Overview and Scope of the Review

This review draws on a broader base of scholarship than the Nigeria-specific literature alone, incorporating comparative evidence on indigenous play from Zambia, Ghana, Cameroon, and Ethiopia, together with theoretical work on ecological psychology, sociocultural development, and decolonial design theory. This wider net serves two purposes. First, it tests whether the patterns observed in the Nigerian literature are idiosyncratic to Nigeria or part of a broader Sub-Saharan African pattern, which strengthens or weakens the claims that can be made from the Nigerian evidence alone. Second, it surfaces theoretical vocabulary, guided participation, cultural affordance, structural versus cosmetic integration, that is needed to move from cultural description toward design and pedagogical implication. The review is organised thematically: it begins with the theoretical foundations that frame play as a culturally situated practice, proceeds to comparative empirical evidence on the developmental value of indigenous play across the region, surveys the specific cultural attributes of the five Nigerian groups at the centre of this paper, turns to the built-environment and design-integration literature, and closes with an explicit synthesis of where consensus, debate, and gap currently sit in the field.

2.2 Theoretical Foundations: Play, Culture, and the Decolonial Critique

The developmental value of play across cognitive, social, emotional, and physical domains is among the most consistently supported findings in early childhood research (Ogunyemi & Henning, 2020). Rogoff (2003) situates these developmental processes within their cultural context, arguing that children's learning cannot be understood apart from the specific cultural practices, tools, and forms of guided participation through which communities organise the activity of their young.

From this perspective, play is not a culturally neutral behaviour that happens to occur within different settings, but a practice whose form, meaning, and developmental function are themselves shaped by cultural tradition.

Gibson's (1979) ecological theory of affordances offers a complementary and more spatially grounded vocabulary, proposing that an environment's developmental value lies not in its physical properties alone but in the relationship between those properties and the cultural knowledge a child brings to interpret them. A courtyard, on this reading, affords storytelling or communal play only to a child equipped with the cultural script that gives its spatial cues meaning, which is precisely what standardised, imported play equipment cannot provide for Nigerian children specifically. Vygotsky's sociocultural theory, as synthesised by Bodrova and Leong (2015), adds a social dimension to this picture through the concept of the zone of proximal development, the space between what a child can do alone and what they can do with the guidance of a more competent other. Applied to indigenous play, this implies that spaces bringing children into contact with elders, older peers, and community members offer a materially richer developmental environment than spaces where children interact only with fixed, solitary equipment.

A decolonial strand of theory sharpens the stakes of this discussion further. Mignolo (2011) and Ndlovu-Gatsheni (2018) argue that colonialism operated as an epistemic project as much as a political one, embedding European institutional and spatial norms as default standards that persist well after formal independence. Kissi (2024) translates this argument into a concrete evaluative distinction for early childhood settings, separating cosmetic decolonisation, the addition of African motifs to an otherwise conventionally organised space or curriculum, from structural indigenous representation, which reorganises practice and space around indigenous logic from the outset. Shabalala (2025) reaches a related conclusion from an environmental-education angle, arguing that African Indigenous Knowledge Systems must be integrated into pedagogy from early childhood onward rather than introduced later as supplementary cultural content, drawing on Ubuntu philosophy and the Southern African proverb Zibanjwa Zisemaphuphu, roughly, that children must be moulded while still young, to make the case that early intervention is where decolonial integration is most consequential. Taken together, this theoretical literature establishes a standard well above simple cultural acknowledgement: it requires that indigenous knowledge shape the fundamental structure of the learning environment, not merely decorate its surface.

2.3 The Developmental Value of Indigenous Play

Comparative Evidence Across Sub-Saharan Africa

Beyond the Nigerian literature, a growing body of empirical work from elsewhere in Sub-Saharan Africa lends independent support to the claim that indigenous play carries genuine developmental value, while also revealing some methodological unevenness worth noting critically. Mwinsa and Dagada (2024), using a participatory action research design with rural preschool teachers in Zambia, found that indigenous games, when used effectively, improved children's literacy and numeracy skills, though teachers reported difficulty executing the games systematically within a formal curriculum, a finding that echoes Egbedeyi's (2024) Nigerian observation that recognising a game's value and being equipped to use it instructionally are two separate things. Yekple et al. (2021), working with an experimental design among the Ewe of Ghana, similarly found that traditional play games measurably developed early literacy and numeracy skills by embedding pattern recognition and narrative comprehension within culturally familiar activity. Lukong and Mbuwir (2024), using an ethnographic and correlational approach in Cameroon, reported that indigenous games strengthened cognitive skills and cultural identity among learners, restoring, in their words, norms and values that prepare children for future adult roles, although their sample was drawn from secondary-school adolescents rather than early childhood populations, which limits how directly their findings transfer to the daycare-age children at the centre of the present review.

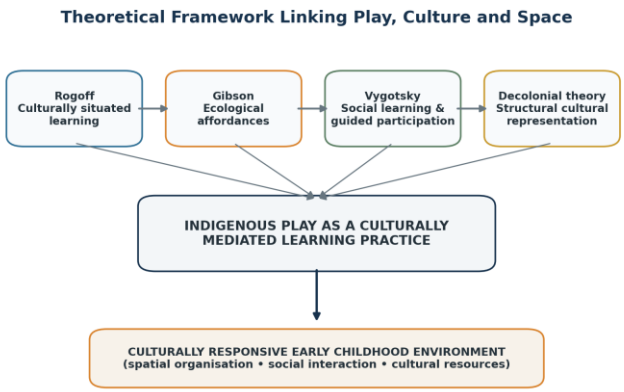


Figure 2. Theoretical framework linking culturally situated play, ecological affordances, social learning and decolonial design.

Source: Author's research work (2026)

Read together, this comparative literature and the Nigeria-specific work of Ogunyemi and Henning (2020) converge on a consistent conclusion: indigenous play is not merely culturally interesting but measurably beneficial for cognitive and literacy-related outcomes across multiple, otherwise quite different, Sub-Saharan African contexts. What the comparison also exposes, though, is a methodological gap within the Nigerian literature specifically. The Zambian and Ghanaian studies (Mwinsa & Dagada, 2024; Yekple et al., 2021) are empirical, field-based, and in Yekple et al.'s case experimental, while the equivalent Nigerian literature, Ogunyemi and Henning (2020) included, remains largely conceptual and argumentative rather than field-tested. This is a genuine limitation of the evidence base this review draws on, and it suggests that the developmental claims made about Nigerian indigenous play traditions specifically, while plausible and consistent with the regional pattern, still await the kind of direct empirical testing that has already been undertaken for Zambian and Ghanaian games.

2.4 Indigenous Nigerian Play Traditions Across Cultural Groups

Yoruba childhood play combines strategic board games, physical games, and oral performance within the spatial setting of the compound courtyard. *Ayo Olopon*, a mancala-family board game played with seeds or stones, is reported to develop numerical reasoning and forward strategic planning, and is typically played before an audience of spectators who comment and evaluate, extending its function beyond cognitive exercise into social performance (Ogunyemi & Henning, 2020; Ekeh, 2024). Physical games such as *Suwe* (a hopscotch variant) and *Ten-Ten* (a rhythmic clapping game) develop coordination and interpersonal synchrony, while *Ere Oṣupa*, moonlight gatherings of children in the compound courtyard for singing, storytelling, and dramatic play, functions as a concentrated setting for cultural transmission (Ekeh, 2024). The oral traditions of *Alo* (riddles), *Itan* (historical narrative), *Oriki* (praise poetry), and *Owe* (proverbs) further embed moral and historical knowledge within playful, participatory performance (Ekeh, 2024). Adeoye et al. (2024) describe the *àárò* courtyard at the centre of the Yoruba *agboole* compound as the primary spatial setting for this activity, a space whose centrality, enclosure, and shade make it simultaneously a domestic, social, and children's play space.

Igbo childhood play is similarly organised around communal, courtyard-based gathering, most prominently expressed in *Egwu Onwa*, moonlight play in which singing, storytelling, riddle competition, and communal games are combined within a single continuous activity (Ekeh, 2024). Documented indigenous games include *Oga*, a competitive jumping game; *Okoso* and *Isong*, seed- and stone-based counting games in the mancala tradition; and *Uri* wrestling, historically associated with preparing young people for community roles. As with Yoruba tradition, these activities are embedded within open, communally accessible compound spaces rather than bounded, equipment-based play areas.

Hausa indigenous play reflects the Islamic cultural context and hierarchical social organisation of Hausa society in northern Nigeria. Documented games include *Caca*, a chance-based game played with cowrie shells that develops probabilistic reasoning; *Kwaikwayo*, dramatic role-play in which children enact adult social roles such as trading and governance; and *Wasan Guje*, competitive running games (Abba, 2023).

The oral traditions of *Waka* (children's play-songs) and *Karin Magana* (proverbs) embed moral and historical knowledge within rhythmic, memorable oral forms. Abba (2023) documents the decline of these oral play traditions in the urban context of northern Nigeria as a consequence of television, digital media, and the displacement of compound-based housing by conventional urban housing forms, a decline with direct relevance to the design of contemporary childcare facilities. Hausa vernacular architecture, characterised by earthen *gida* compounds organised around shaded internal courtyards, provides the primary spatial precedent for this activity (Dada & Alibaba, 2023).

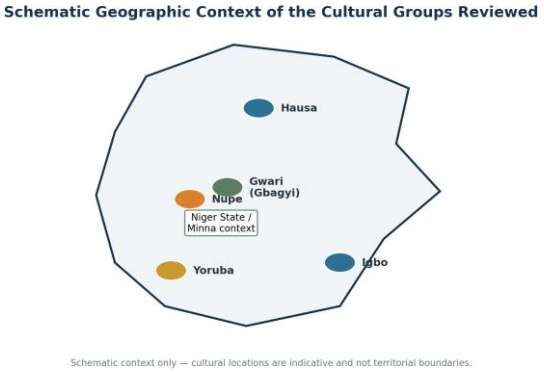


Figure 3. Schematic geographic context of the cultural groups examined in the review; locations are indicative rather than territorial boundaries.
Source: Author's research work (2026)

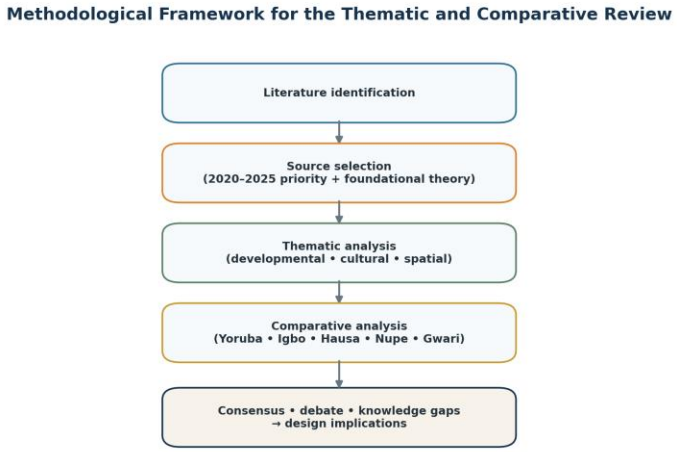


Figure 5. Methodological framework for the thematic and comparative literature review.

Source: Author's research work (2026)

Table 2. Visual translation of the comparative cultural findings into preliminary spatial implications.

Cultural group	Representative play	Cultural / developmental function	Spatial implication
Yoruba	Ayo Olopon; moonlight play	Strategy, oral tradition, social participation	Courtyard / shaded communal space
Igbo	Egwu Onwa; communal games	Storytelling, cooperation, role-play	Flexible communal gathering space
Hausa	Caca; Kwaikwayo; Wasan Guje	Reasoning, social roles, oral tradition	Shaded courtyard / role-play space

Nupe	Craft apprenticeship	Intergenerational learning, craft knowledge	Craft / making activity area
Gwari (Gbagyi)	Pottery, music, craft	Cultural knowledge, communal activity	Craft and communal activity space

Source: Author's research work (2026)

As the indigenous inhabitants of the Minna region and much of Niger State, the Nupe and Gwari (Gbagyi) peoples contribute cultural attributes of particular local relevance. Nupe cultural life is closely associated with craft production, including metalwork, beadwork, and woven textiles, learned through intergenerational apprenticeship relationships that begin in childhood, together with a tradition of proverbs and riddles used as tools for moral and social instruction (Dada & Alibaba, 2023). Gwari cultural life is similarly expressed through music, pottery, and craft-making, situated within the rounded, earth-built compound forms characteristic of Gwari vernacular architecture (Olulode, 2022). Relative to Yoruba, Igbo, and Hausa traditions, Nupe and Gwari play practices remain comparatively underdocumented in the scholarly literature, a gap this review identifies as a priority for future empirical research.

2.5 The Built Environment and the Persistent Design Gap

Despite the developmental and cultural significance of these traditions, evidence suggests they remain marginal to the design and pedagogy of contemporary Nigerian early childhood facilities. Egbedeyi (2024), in a study of teachers' awareness and utilisation of indigenous games as instructional resources in Ondo West Local Government, found that while teachers generally recognise the developmental value of indigenous games, their systematic use as instructional resources in formal early childhood settings remains limited. Oyegoke et al. (2024) similarly argue for a framework of culturally relevant pedagogy in Nigerian early childhood education that gives equal recognition to indigenous and Western play-based learning practices, noting that current practice continues to privilege imported models. At the level of the built environment, Emmanuel and Abdullahi (2025), in a study of the design of a child-conscious recreation centre in Abuja, demonstrate that architectural design decisions directly shape the extent to which play spaces support learning, parental engagement, and culturally meaningful activity, offering a design-oriented precedent for the integration of indigenous cultural attributes into early childhood facility planning.



Figure 4. Representative indigenous play and cultural activities across the five cultural groups reviewed.

Source: Author's research work (2026)

This pattern is not unique to Nigeria. Amissah-Essel et al. (2020), assessing the physical environments of 160 early childhood care and development centres in the Cape Coast Metropolis of Ghana using a modified Children's Physical Environment Rating Scale, found that outdoor play yards in particular fell short of children's functional and developmental needs, with just over half of centres rating only fair overall, independent of whether the centre was privately or publicly run.

This is a valuable comparative anchor for the present review because it is one of the few studies in the regional literature to measure environmental quality directly rather than relying on teacher or designer testimony, and it corroborates, from an entirely different West African country and methodology, the same basic pattern that Egbedeyi (2024) and Oyegoke et al. (2024) describe qualitatively for Nigeria: recognition of what a good play environment requires has outpaced the ability, or perhaps the institutional will, to build it. Jirata (2019), in an ethnographic study of the Guji people of Ethiopia, adds a further dimension by showing that indigenous African play is often distributed across the everyday landscape of a community, the compound yard, the field, the waterway, rather than concentrated in a single bounded play area, which complicates the common Western planning assumption that a play space should be a single, purpose-built zone.

International participatory design literature offers a useful, if geographically distant, point of comparison for how this gap might be closed. Brussoni et al. (2025), reporting on the PRO-ECO 2.0 programme in British Columbia, found that outdoor play environments co-designed with Indigenous Knowledge Keepers from the earliest stages of design differed qualitatively from spaces conventionally designed and then adjusted for cultural content. Sofija et al. (2024) reached a broadly similar conclusion in an Australian context, co-designing a nature play programme with culturally and linguistically diverse families. Wai et al. (2020) provide a theoretical bridge relevant to both contexts, arguing that children's engagement with culturally specific objects and materials generates stronger cultural identity formation than engagement with culturally neutral equipment, a claim consistent with the Nigerian oral-tradition evidence reviewed above. Yücesan et al. (2023), in a systematic review of cultural heritage integration in early childhood education, found that the most effective integration treats cultural artefacts as functional, handleable play resources rather than as static display items, a finding with a direct implication for how indigenous Nigerian game objects, Ayo boards, cowrie shells, craft materials, might be incorporated into daycare design rather than simply referenced in curriculum.

2.6 Synthesis

Consensus, Debate, and the Knowledge Gap

Read across rather than within, this literature shows a reasonably clear pattern of consensus alongside at least one unresolved debate and a set of specific gaps. The consensus is that indigenous play carries genuine, not merely symbolic, developmental value, a conclusion now supported independently by evidence from Nigeria (Ogunyemi & Henning, 2020), Zambia (Mwinsa & Dagada, 2024), Ghana (Yekple et al., 2021), and Cameroon (Lukong & Mbuwir, 2024), and reinforced theoretically by Rogoff's (2003) account of culturally situated learning and Gibson's (1979) account of culturally mediated affordance. The debate concerns where the barrier to integration actually sits. Egbedeyi (2024) and Oyegoke et al. (2024) locate it primarily in pedagogy and institutional practice, teacher training, curricular privilege, while the present review's architectural framing, supported by Amissah-Essel et al.'s (2020) direct measurement of substandard play-yard quality in Ghana, suggests the barrier may be at least partly spatial: a teacher persuaded of a game's value has limited means of acting on that conviction in a facility with no courtyard, no shaded gathering space, and no sightline connecting indoor and outdoor zones. Neither position has yet been tested against the other directly, which is itself a notable gap in the literature.

Three further gaps follow from this synthesis and are addressed directly in the remainder of this paper. First, the Nigerian evidence on the developmental value of indigenous play remains comparatively conceptual next to the empirically tested Zambian and Ghanaian literature, a limitation this review inherits rather than resolves. Second, Nupe and Gwari play traditions remain markedly underdocumented relative to Yoruba, Igbo, and Hausa traditions, even within the Nigerian literature itself, which limits how confidently this review's comparative claims can be extended to all five focal groups equally. Third, and most directly relevant to this paper's contribution, no study identified in this review, Nigerian, regional, or international, completes the translation from documented cultural attribute to spatial design criterion for the daycare building type specifically; Kissi's (2024) cosmetic-structural distinction supplies the evaluative standard for that translation, but has not yet been operationalised into design guidance. The Results and Discussion sections that follow take up this third gap as their central task.

3. Methodology

This paper adopts a thematic and comparative literature review methodology consistent with its aim of synthesising dispersed scholarship on indigenous play traditions and early childhood environments in Nigeria and, comparatively, in wider Sub-Saharan Africa. Literature was drawn from research on indigenous knowledge systems, childhood play, cultural practice, environmental learning, and child development, spanning the disciplines of education, developmental psychology, architecture, and Nigerian cultural studies. Priority was given to peer-reviewed sources published between 2020 and 2025, supplemented by foundational theoretical works where relevant to establishing the cultural and developmental framing of play. Sources were analysed thematically to identify recurring patterns across the developmental, cultural, and spatial dimensions of indigenous play, following the general principles of thematic analysis (Braun & Clarke, 2022). A comparative analytical structure was then applied across the five focal cultural groups, Yoruba, Igbo, Hausa, Nupe, and Gwari, and, where relevant, against comparable evidence from Zambia, Ghana, Cameroon, and Ethiopia, to identify both shared patterns and group-specific attributes relevant to the design of early childhood environments.

4. RESULTS

The thematic and comparative review yielded four recurring findings, summarised for the five focal cultural groups in Table 1.

First, indigenous Nigerian play traditions consistently combine cognitive, social, physical, and moral developmental functions within a single activity, in contrast to the more narrowly targeted developmental functions of much manufactured play equipment, a pattern corroborated by comparative evidence from Zambia and Ghana (Mwinsa & Dagada, 2024; Yekple et al., 2021). Second, oral tradition, storytelling, proverb, riddle, and praise poetry, functions as a primary mechanism of cultural transmission embedded directly within play activity across all five cultural groups. Third, indigenous play is characteristically communal and intergenerational, organised within open, socially accessible compound and courtyard spaces rather than bounded, single-age play zones, a pattern with direct implications for the spatial design of childcare facilities and consistent with Jirata's (2019) account of distributed, landscape-embedded play in Ethiopia. Fourth, despite consistent evidence of developmental value, indigenous play traditions remain marginal to the design, pedagogy, and management of contemporary Nigerian early childhood facilities, with only a small and recent body of scholarship beginning to address this gap directly (Egbedeyi, 2024; Oyegoke et al., 2024; Emmanuel & Abdullahi, 2025), a pattern that Amissah-Essel et al.'s (2020) direct measurement of play-yard quality in Ghana suggests is regional rather than uniquely Nigerian.

Table 1. Comparative Summary of Indigenous Play Traditions Across Selected Nigerian Cultural Groups

Cultural Group	Representative Play Traditions	Cultural Learning Attributes	Key Sources
Yoruba	Ayo Olopon, Suwe, Ten-Ten, Ere Oṣupa (moonlight play)	Riddles (Alo), praise poetry (Oriki), proverbs (Owe), historical narrative (Itan)	Ekeh (2024); Ogunyemi & Henning (2020); Adeoye et al. (2024)
Igbo	Egwu Onwa (moonlight play), Oga, Okoso, Isong, Uri wrestling	Storytelling, riddle competition, communal role-play	Ekeh (2024)
Hausa	Caca, Kwaikwayo, Wasan Guje	Play-songs (Waka), proverbs (Karin Magana)	Abba (2023); Dada & Alibaba (2023)
Nupe	Craft-based apprenticeship play (metalwork, beadwork, weaving)	Proverbs and riddles used for moral and social instruction	Dada & Alibaba (2023)
Gwari (Gbagyi)	Music, pottery, craft-making	Indigenous knowledge transmitted through craft and communal activity	Olulode (2022)

Source: Author's research work (2026)

The comparative structure of Table 1 highlights both the shared character of indigenous Nigerian play, communal, orally mediated, and intergenerational, and the distinct cultural vocabulary each group brings to it, from the Yoruba board game and moonlight gathering to the Hausa role-play and proverb tradition to the craft-centred learning of the Nupe and Gwari. The thinner evidentiary column for Igbo, Nupe, and Gwari traditions relative to Yoruba is itself a finding, reflecting the uneven documentation identified in the literature review rather than a genuine absence of cultural material.

5. DISCUSSION

The findings of this review carry three principal implications for the planning, design, and management of early childhood environments in Nigeria. First, because indigenous play traditions are organised around communal, courtyard-based spatial forms rather than bounded, single-function play equipment, culturally responsive design should prioritise flexible, communally accessible outdoor spaces capable of accommodating storytelling, dramatic role-play, and group games, rather than replicating the isolated equipment stations typical of imported playground models. Second, because oral tradition functions as a primary mechanism of cultural transmission within indigenous play, early childhood pedagogy and facility programming should create structured opportunities for storytelling, proverb exchange, and intergenerational interaction rather than treating indigenous games solely as recreational activities to be scheduled alongside a Western curriculum. Third, the comparative unevenness identified in this review, with Yoruba, Igbo, and Hausa traditions considerably better documented than Nupe and Gwari traditions, indicates a need for further empirical, community-based research to establish a fuller and more locally grounded evidence base for culturally responsive design in north-central Nigeria specifically.

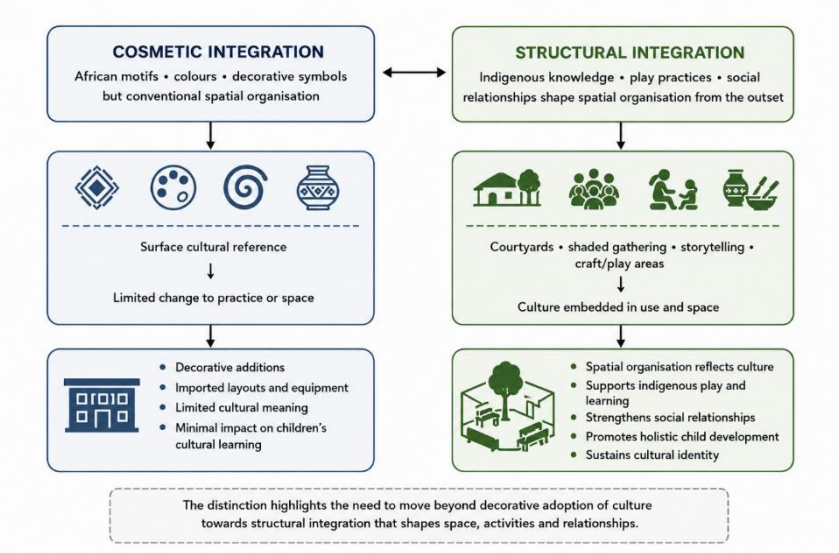


Figure 7. Translation of indigenous play traditions into spatial design criteria for early childhood environments.

Source: Author's research work (2026)

The debate identified in the literature review, over whether the persistent gap between recognised value and actual practice is primarily pedagogical or architectural, cannot be fully resolved by a literature-based review of this kind, but the regional evidence assembled here tilts the argument toward treating it as at least partly spatial. If Ghanaian centres with presumably comparable levels of teacher awareness to Nigerian ones still produce substandard play yards at scale (Amissah-Essel et al., 2020), then teacher training and curricular reform alone are unlikely to be sufficient; the built environment itself has to change. This is a modest but real refinement of the more pedagogy-centred diagnoses offered by Egbedeyi (2024) and Oyegoke et al. (2024), and it is consistent with the decolonial distinction Kissi (2024) draws between cosmetic and structural integration, since a curriculum reform layered onto an unchanged, equipment-based play yard would itself be a cosmetic rather than structural intervention.

These implications should be read in light of the review's limitations. As a literature-based synthesis rather than an empirical field study, the review is dependent on the depth and currency of existing scholarship, which, as noted above, is markedly uneven across the five cultural groups and, in the Nigerian case specifically, weighted toward conceptual argument rather than field-tested evidence relative to comparable Zambian and Ghanaian studies. The review is further limited to English-language, primarily academic sources, which may underrepresent oral and community-held knowledge that has not been documented in the scholarly literature. These limitations reinforce, rather than undermine, the case for further empirical research directly engaging Nigerian cultural communities in the documentation and design application of their play traditions.

6. CONCLUSION

This review has shown that indigenous play traditions across the Yoruba, Igbo, Hausa, Nupe, and Gwari cultural groups constitute a substantial and developmentally significant cultural resource, combining cognitive, social, physical, and moral benefits with powerful mechanisms of cultural transmission and identity formation, a conclusion strengthened by convergent evidence from Zambia, Ghana, and Cameroon rather than resting on Nigerian sources alone. Despite this significance, the reviewed literature indicates that these traditions remain largely excluded from the design, pedagogy, and management of contemporary early childhood facilities in Nigeria, a pattern that comparative evidence from Ghana suggests is regional rather than uniquely Nigerian, and that decolonial theory (Kissi, 2024; Mignolo, 2011; Ndlovu-Gatsheni, 2018) frames as a structural rather than incidental omission. The paper recommends the greater integration of indigenous cultural knowledge into the planning, design, and management of early childhood environments, and identifies the comparative scarcity of empirical, design-focused research on Nupe and Gwari play traditions, the absence of field-tested developmental evidence for Nigerian indigenous games specifically, and the unresolved question of whether the persistent value-practice gap is primarily pedagogical or architectural, as priority areas for future research.

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DAYLIGHTING DESIGN STRATEGIES FOR TROPICAL ARCHITECTURE STUDIOS: A SYSTEMATIC REVIEW

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ABSTRACT
Architecture studios in tropical regions require high-quality daylight for visually intensive design processes, but high solar availability can also produce glare, solar heat gain and non-uniform light distribution. This systematic review synthesizes evidence on passive daylighting strategies for tropical architecture studios from 15 eligible studies identified through a PRISMA-guided review process. A search of 440 records across five databases identified studies addressing window geometry, shading systems, surface reflectance and spatial configuration in relation to daylight distribution, visual comfort and glare control. The included studies indicate that louvres and light shelves can balance daylight admission and glare reduction, although performance depends strongly on orientation, solar geometry and time of day. High-level windows and clerestory apertures can improve daylight penetration into deeper studio spaces, but may require appropriate shading to limit glare and excessive solar exposure. Surface reflectance and spatial arrangement also influence daylight distribution and occupant perception. Across the evidence, no single strategy provides a universal solution; effective performance depends on the interaction of window geometry, shading, reflectance and spatial configuration. The limited number of longitudinal occupant studies and the reliance on simulation without field validation in several studies indicate a need for standardized tropical daylighting measurements, post-occupancy evaluation and greater integration of objective performance metrics with occupant perception.
Keywords: Daylighting, Tropical Architecture, Design Studios, Visual Comfort, Systematic Review

INTRODUCTION
Daylighting strongly shapes occupant well-being, visual comfort, and energy performance, and is especially critical in architecture studios, where tasks such as drawing, model-making, and colour evaluation demand accurate, consistent illumination (Shafavi et al., 2020). Tropical climates, with their high solar altitude angles and abundant direct sunlight, offer ample daylight but also intense glare, overheating, and non-uniform light distribution, which can undermine comfort and increase cooling loads (Khaire et al., 2026). Because artificial lighting already accounts for a significant share of building energy use, and cooling loads in the tropics are already high (González-Torres et al., 2022), poorly resolved daylighting strategies carry both an energy and a pedagogical cost: studios are living laboratories where students learn sustainable design by direct experience, and access to natural light is linked to improved mood, concentration, and academic performance (Heschong et al., 2002).
Despite growing interest in tropical daylighting, most existing research addresses generic offices or residential buildings rather than the specific visual demands of design studios (Wan Abdullah et al., 2019), and studio-focused studies often rely on simulation without field validation (Ayoosu et al., 2025). Daylighting and thermal comfort are also frequently treated separately, even though in tropical climates a strategy that improves daylight can simultaneously worsen heat gain (Salem Bahdad et al., 2022). This review addresses these gaps by systematically synthesizing evidence on daylighting design strategies for tropical architecture studios, identifying the design parameters that most influence visual comfort and glare control, and highlighting priorities for future research and practice.

RESEARCH AND FINDINGS
Methodology
This review followed the PRISMA 2020 reporting framework (Page et al., 2021). Literature was searched across Scopus, ScienceDirect, Web of Science, SpringerLink, and Google Scholar using terms combining daylighting, design strategies, tropical climate, and studio environments.

The principal search string combined “daylighting” OR “natural lighting” with “design strategies” OR “passive design”, “tropical” OR “hot humid”, and “studio” OR “architecture studio”. Eligible studies examined daylighting strategies in architecture/design studios located in tropical climates, reported original empirical or simulation-based analysis, and were peer-reviewed. Studies on non-studio buildings, non-tropical contexts, opinion pieces, theses, and preprints were excluded. Two reviewers independently screened titles/abstracts and full texts, with disagreements resolved by consensus. Study quality was appraised using five predefined dimensions: methodological clarity, appropriateness of study design, transparency of methods, adequacy of performance/measurement assessment, and relevance to the review question. Of 440 records identified, 248 remained after de-duplication; 51 passed title/abstract screening, 41 were retrieved in full text, and 15 studies met the stated inclusion criteria.

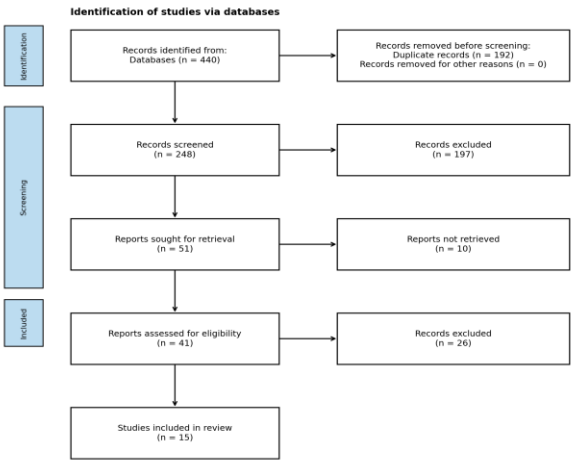


Figure 1. PRISMA flowchart of the study selection process

Results

The 15 included studies indicate a relatively small and geographically concentrated evidence base, with several recent studies appearing from 2021 onward (Figure 2). Because bibliographic details were verified and corrected, the revised year distribution should be interpreted from the corrected reference list. This pattern suggests renewed scholarly attention driven by climate-responsive design and post-pandemic interest in indoor environmental quality, though the overall evidence base remains small.

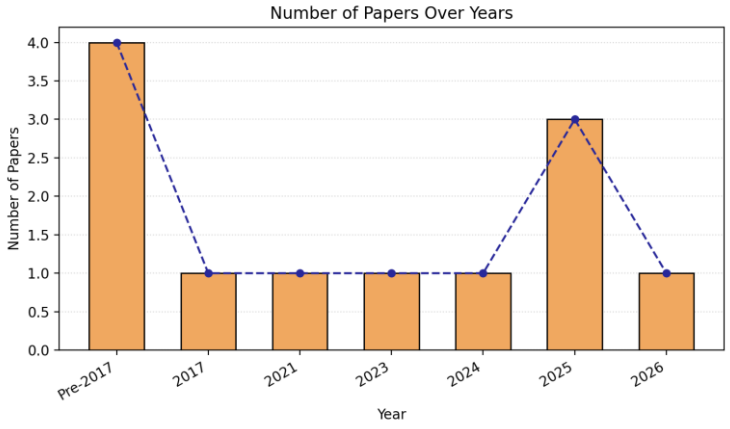


Figure 2. Distribution of publications by year

Table 1 summarizes the design, context, strategy, and key findings of each included study.

Study	Design / Context	Strategy	Key Metrics	Key Finding
Achsani et al. (2025)	Field measurement, 5 days; deep side-lit studio	Side lighting; view/zone/layout variation	Vertical eye illuminance (Ev), DGP	Comfort depends on view direction, zone, layout, time; perimeter >> core; optimum at midday, south perimeter, semi-enclosed layout
Ahsan (2026)	Simulation; DUET, Gazipur studio	Window size, light shelf, reflector	Daylight distribution, uniformity	Proposed to enhance daylighting; full results not detailed in abstract
Aman (2017)	Simulation + survey; Dhaka studios	Window size/orientation/shading; CBDM (DAYSIM)	PPD, daylight/thermal outputs	Combined thermal-daylight simulation to identify effective window type; results not detailed
Anggita (2026)	Observation + interview; Pancasila Univ. studio	Daylighting implementation	Illumination level	Existing daylight inadequate; linked to student health/productivity; design concept proposed
Mohd Ariffin & Eleyan (2021)	Field measurement + survey; IIUM (KAED) studios	LED retrofit	Lighting level, energy use	Lighting below standard but comfort unaffected; LED retrofit cuts energy ~40%, 5-yr payback
Bramiana et al. (2025)	Simulation (Revit); generic studio	Louvre angle (0–45°)	Glare, illuminance	Flat angles raise morning light and glare; steep angles cut glare and light; moderate angles best at midday
Fathan et al. (2026)	Field + DIALux + survey; Surabaya (ITS) studios	Surface reflectance	Illuminance, perception	Reflectance strongly predicts illuminance (R^2=.77); users adapt to sub-standard levels; satisfaction predicts productivity (β=.74)

Study	Design / Context	Strategy	Key Metrics	Key Finding
Ibrahim (2012)	Simulation (Radiance); Malaysian teaching studio	Ceiling/window head height	Daylight level	Ceiling and window-head variation shifts achievable daylight range
Khan et al. (2026)	Case study + simulation (ClimateStudio); Dhaka university	Spatial reconfiguration + PV-ETFE envelope	Illuminance, sDA, ASE, LEED credits	Illuminance rose 410→921 lux; sDA rose 46%→76.3%; achieved maximum LEED daylighting credits
Mohammed (2026)	Survey + measurement + Dialux; Nigerian studio	High-level windows/clerestory	DGP, uniformity, illuminance	72–73% reported dissatisfaction; simulation shows high windows/clerestory raise illuminance toward 500 lux target
Sancho-Salas et al. (2024)	Survey (n=153); Costa Rica & Malaysia schools	Solar-geometry teaching methods	Self-assessed knowledge	Low self-assessed solar-geometry knowledge; preference for blended manual/digital tools
Sharmin (2011)	Literature + survey + simulation; Bangladesh studios	Luminous-environment features	—	Studios rely on artificial light despite abundant daylight; no local lighting standard exists
Soud & Hossain (2017)	Simulation; Dhaka adapted studio	Light shelves	Work-plane illuminance	6-ft, 40-in light shelves outperform no-shelf alternative for meeting standards
Sultana (2023)	Case study; Chattogram studio	Windows	Illuminance	Adequate on clear days; artificial lighting needed when overcast
Tsou et al. (2000)	Problem-based learning; Hong Kong	Natural lighting / solar-control pedagogy	—	Emphasizes qualitative synthesis over quantitative analysis; critical use of visualization tools needed

Across studies, window geometry and shading emerge as the most consistently investigated parameters. High-level windows and clerestory openings improve daylight penetration in deep studios but risk glare and non-uniformity unless paired with adjustable shading (Mohammed, 2026; Ibrahim, 2012). Louvre and light-shelf studies show a clear trade-off: flatter shading angles admit more morning light but increase glare, while steeper angles control glare at the cost of illuminance; performance is highly sensitive to solar altitude and orientation, so adjustable or seasonally calibrated shading may offer advantages over fixed configurations (Bramiana et al., 2025; Soud & Hossain, 2017). Surface reflectance also showed a strong relationship with indoor illuminance, suggesting a potentially low-cost complementary strategy that can improve daylight distribution without major modification of the building envelope (Fathan et al., 2026). A more integrated approach combining spatial reconfiguration with a photovoltaic-integrated envelope produced substantial simulated gains, with illuminance nearly doubling and spatial daylight autonomy rising from 46% to 76.3%; however, the results lacked field validation (Khan et al., 2026). Other studies confirm that windows adequate on clear days often require artificial supplementation under overcast skies (Sultana, 2023), and that many tropical studios remain reliant on artificial lighting despite abundant daylight, with no formal studio-lighting standards in place (Sharmin, 2011).

User-perception evidence complicates a purely metric-based view of daylighting quality. In Indonesia, users rated sub-standard measured illuminance as "neutral," suggesting adaptation to existing conditions, while satisfaction still strongly predicted self-reported productivity (β=.74, $p<.001$) (Fathan et al., 2026). In Nigeria, by contrast, most respondents reported dissatisfaction with brightness and distribution despite acceptable simulated glare and uniformity values (Mohammed, 2026), indicating that perception is shaped by more than any single objective metric. Educational-context studies reinforce this: students in Costa Rica and Malaysia reported low self-assessed knowledge of solar geometry despite recognizing its importance, and favoured blended manual/digital teaching tools (Sancho-Salas et al., 2024), while a Hong Kong problem-based learning study argued that studio pedagogy should prioritize qualitative synthesis over quantitative analysis, using simulation tools critically rather than uncritically (Tsou et al., 2000). Table 2 summarizes user-perception and educational-context evidence.

Study	User Group / Context	Assessment Method	Key Implication
Fathan et al. (2026)	Studio users, Surabaya	Likert questionnaire + field measurement	Reflectance predicts illuminance; users adapt; satisfaction predicts productivity
Mohammed (2026)	Studio respondents, Nigeria	Questionnaire + measurement	Majority dissatisfied with brightness/distribution; recommends design strategies
Anggita (2026)	Architecture students, Pancasila Univ.	Interview + observation	Daylight linked to health/productivity; design concept proposed
Tsou et al. (2000)	Students, Hong Kong studio education	Problem-based learning	Qualitative synthesis prioritized over quantitative analysis
Sancho-Salas et al. (2024)	Students, Costa Rica & Malaysia	Survey (n=153)	Low solar-geometry knowledge; blended learning preferred
Sharmin (2011)	Not specified, Bangladesh studios	Field survey + simulation	No studio-lighting standard exists; recommends design strategies

Study	User Group / Context	Assessment Method	Key Implication
Mohd Ariffin & Eleyan (2021)	Studio users, IIUM (KAED)	Questionnaire + lux-meter	Sub-standard lighting did not reduce comfort; LED retrofit proposed (40% saving)

DISCUSSION

Taken together, the included evidence indicates that no single passive strategy consistently resolves the tropical studio's tension between providing adequate daylight for visually demanding tasks and controlling glare and solar heat gain. Effective daylighting instead depends on calibrated interaction among window geometry, shading, reflectance, and spatial layout, tuned to local solar geometry and orientation—pointing practitioners toward annual, climate-based simulation (e.g., ClimateStudio, DAYSIM) rather than single-point analysis, and toward adjustable rather than static shading. The discrepancy between objective metrics and subjective satisfaction found across some studies cautions against treating a single illuminance value, such as 500 lux, as a universal indicator of daylight quality. Illuminance should be interpreted alongside distribution, glare, task requirements, sky conditions and occupant perception. For educators, the documented gap in students' solar-geometry knowledge suggests that studios themselves should model the sustainable-design principles being taught, supported by teaching tools that blend physical/manual methods with digital simulation.

These conclusions should be read against several limitations: the English-language restriction may have excluded relevant non-English literature; the small evidence base (n=15) and its concentration in South/Southeast Asia and West Africa limit generalizability to other tropical regions (e.g., the Americas, the Pacific, or high-altitude East Africa); and heavy reliance on simulation without field validation raises questions about real-world accuracy. Priority directions for future research include longitudinal field studies linking continuous physical monitoring to repeated occupant surveys, tropical-specific “adaptive comfort” daylighting metrics, integration of daylighting with natural ventilation and operable shading (almost entirely unstudied to date), and further cross-cultural comparative work extending beyond the Costa Rica–Malaysia comparison to determine whether daylighting design principles are universal or context-specific.

CONCLUSION

This review synthesized evidence from 15 studies to clarify how passive design strategies can reconcile daylight admission with glare control in tropical architecture studios. Effective daylighting depends on an integrated combination of high-level windows, adjustable shading, and high-reflectance surfaces—no single parameter offers a universal solution—and user adaptation in tropical contexts means that objective illuminance levels do not always align with subjective satisfaction. Practitioners should use climate-based simulation where appropriate and interpret daylight performance alongside point-in-time measurements and occupant needs. Educators should also address gaps in solar-geometry knowledge through blended teaching tools, recognizing that the studio environment can itself model sustainable-design principles. Future work should prioritize longitudinal field validation, tropical-specific adaptive-comfort metrics, and cross-cultural comparative studies across underrepresented tropical regions.

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REDUCED GRAPHENE OXIDE-INTEGRATED COPPER ALUMINATE NANOCOMPOSITE FOR HIGH-PERFORMANCE SUPERCAPACITORS

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ABSTRACT
Transition metal-based spinel oxides are fascinating supercapacitor electrode materials due to their good specific capacitance and cost-effectiveness. But the spinel materials show poor cycling stability due to their limited surface area. This issue was reduced by using carbon-based electrode materials such as rGO, which enhances the electroactive surface area, leading to improve the number of reactive sites. In this research, a simple hydrothermal approach was utilised to synthesise the $CuAl_2O_4$/rGO nanocomposite. It was successively characterised with different analytical techniques to study the physicochemical properties of the synthesised materials. Additionally, the potential of the materials as electrodes was determined with a three-electrode configuration by utilising different electrochemical tools that were performed to assess the characteristics of the electrode material. The synthesised nanocomposite exhibits a magnificent specific capacitance of 1206.14 F/g at 1 A/g, while demonstrating specific energy of 34.83 Wh/kg and specific power of 228 W/kg, which is higher than that of individuals and also shows a high retention capacitance value of 93.36% after 8000th charge/discharge cycles. The symmetric behaviour of the fabricated electrode is also determined with two electrode systems exhibiting the specific energy and specific capacitance of 16.54 Wh/kg and 601.91 F/g, respectively. This study demonstrates that incorporating rGO into $CuAl_2O_4$ nanoarray improves energy storage performance, and it has the potential to work in other energy storage devices.
Keywords: $CuAl_2O_4$/rGO nanocomposite, Electrode material, Hydrothermal method, Supercapacitor

ECO-FRIENDLY SYNTHESIS OF CHITOSAN@TiO_2 NANOCOMPOSITE FOR EFFICIENT DYE ADSORPTION AND TEXTILE WASTEWATER TREATMENT: A COMBINED EXPERIMENTAL AND THEORETICAL STUDY

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ABSTRACT

Background
The textile industry generates substantial volumes of dye-contaminated wastewater, posing severe environmental and health risks due to the persistence, toxicity, and resistance to biodegradation of synthetic dyes such as Crystal Violet (CV) and Methylene Violet (MV). This study aimed to develop a sustainable and efficient nanocomposite adsorbent by combining green-synthesized titanium dioxide (TiO_2) nanoparticles with chitosan (CS) to address the limitations of conventional dye removal methods, including high cost, energy consumption, and generation of harmful by-products.

Methods
TiO_2 nanoparticles were synthesized via a green route using crude aqueous ginger extract, with synthesis optimized by a Box–Behnken design considering extract volume (1–5 mL), titanium precursor concentration (0.1–0.5 M), and calcination temperature (400–500 °C). The optimized TiO_2 nanoparticles were immobilized in chitosan beads to fabricate the CS@TiO_2 nanocomposite. The material was characterized by FTIR, XRD, SEM-EDS, BET, and pH_{PZC} analyses. Adsorption performance was evaluated through kinetic, isotherm, thermodynamic, reusability, and DFT studies, and validated using real textile wastewater.

Findings
The optimal synthesis conditions (5 mL CAE volume, 0.3 M precursor concentration, calcination at 400 °C) yielded mesoporous TiO_2 nanoparticles with a high BET surface area of 150.49 $m^2\ g^{-1}$ and an average particle size of 10.38 nm.

Incorporation into chitosan further enhanced the surface area to 201.24 $m^2 g^{-1}$ with a well-developed mesoporous structure (average pore diameter: 8.25 nm). The CS@TiO_2 nanocomposite demonstrated rapid adsorption equilibrium within 120 min, following pseudo-second-order kinetics (R^2 = 0.992 for CV, R^2 = 0.989 for MV). Langmuir isotherm provided the best fit, with maximum adsorption capacities of 165.84 mg g^{-1} for CV and 132.84 mg g^{-1} for MV. Thermodynamic analysis confirmed spontaneous, endothermic adsorption ($\Delta G°$ = −6.26 to −7.84 kJ/mol for CV; $\Delta G°$ = −3.86 to −4.59 kJ/mol for MV). DFT calculations revealed enhanced electronic properties upon TiO_2 incorporation (HOMO–LUMO gap reduced from 5.27 to 1.20 eV), with CV exhibiting stronger electron-donating capacity and higher global softness (1.65 eV^{-1}) compared to MV (0.26 eV^{-1}). Application to real textile wastewater achieved remarkable removal efficiencies: 87.75% for COD, 75.00% for BOD_5, and 98.35% for electrical conductivity, with near-complete decolorization. The nanocomposite maintained appreciable reusability, retaining 67.77% removal efficiency for CV after five cycles. These findings establish CS@TiO_2 as an efficient, eco-friendly, and reusable adsorbent for sustainable textile wastewater treatment.

Keywords*:* Adsorption, Chitosan, TiO_2 nanoparticles, Green synthesis, Wastewater treatment, Crystal Violet, Methylene Violet.

MYCOCHEMICAL PROFILING, ANTIOXIDANTS PROPERTIES AND ANTIBACTERIALAL ACTIVITIES OF ETHYL ACETATE EXTRACT OF BONDARZEWIA BERKELEYI

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ABSTRACT

Mushrooms are known to contain a wide range of bioactive compounds that contribute to their medicinal properties, including antioxidant and antimicrobial activities. This study investigated the mycochemical composition, antioxidant potential, and antibacterial activity of the ethyl acetate extract of *Bondarzewia berkeleyi*, a non edible mushroom harvested from the Bayero University Old Campus in August 2025, identified at herbarium with number BUKHAN 00652. Identified *Streptococcus pyogenes*, *Pseudomanas aeruginosa* and *Salmonella typhi* were obtained from Department of Microbiology Bayero University Kano.

Sequential ultrasound assisted extraction was carried out with *n*-hexane, ethyl acetate and methanol respective. The ethyl acetate fraction was subjected to mycochemical profiling, antioxidant activities, using DPPH radical scavenging assay, while antibacterial activity was evaluated using the agar well-diffusion method. Minimum inhibitory concentration (MIC) was determined on Meuller-Hinton media in triplicates of various concentrations of the extract and inhibition zones measured in millimeter. Ciprofloxacin was used as standard.

Mycochemicals detected are saponins (1.906±0.036 mg/g), steroids (2.342±0.024 mg/g), cardiac glycosides (0.154±0.010 mg/g), terpenoids (1.020±0.011 mg/g), alkaloids (0.323±0.004 mg/g) and flavonoids (1.215±0.015 mg/g).

The extract demonstrated moderate antioxidant activity with a DPPH IC_{50} value of 231.33±50.52 µg/ml compared to ascorbic acid (0.00133±0.00058 µg/mL). Antibacterial assays showed inhibitory effects against *Streptococcus pyogenes* (10.01±0.04 to 16.10±1.02), *Pseudomanas aeruginosa* (7.03±0.05 to 12.11±1.02) S*almonell typhi* (9.05±0.04 to 14.13±1.03) from 500 mg/ml to 4000 mg/ml extract concentration.

These findings suggested that *B. berkeleyi* is a promising source of bioactive compounds with potential of developing natural antioxidants and antibacterial medicaments.

EXPLORING THE LINK BETWEEN SERUM MYOSTATIN AND SARCOPENIA IN MIDDLE-AGED ADULTS

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ABSTRACT

Introduction: Myostatin levels in individuals increase with age, resulting in reduced muscle mass and decreased strength, which contributes to the development of sarcopenia.

Objectives: To find and compare the levels of Myostatin in middle-aged Sarcopenic and non-Sarcopenic individuals.

Materials and Methods: This cross-sectional study employed purposive sampling and was conducted in the Department of Physiology at Khyber Medical University from October 26, 2023, to March 19, 2024. The OpenEpi software was used to determine the sample size with 80% power and a 95% confidence level. Ninety-two volunteers (male=58, female=34) were included in the study, which used the SWAG-SARCO 2021. Myostatin levels were measured using an enzyme-linked immunosorbent assay. The exercise tests were performed in the skill labs at IBMS, KMU, and BKMC Mardan.

Results: A statistically significant difference ($p < 0.05$) was observed between the patients in the Sarcopenia group and those in the non-Sarcopenia group regarding MUAC, TSF, CC, height, weight, and BMI. In addition, a statistically significant difference ($p < 0.05$) was also found between the sarcopenia group and the non-sarcopenia group in terms of SPPB, Grip strength, IRM-Knee extension, weightlifting, Quad stretch, and TUG test. The mean myostatin levels between the sarcopenic and non-sarcopenic groups were also statistically significant ($p = 0.001$).

Conclusion: This study showed that even among middle-aged individuals, myostatin levels may increase, leading to an involuntary loss of skeletal muscle strength and mass known as sarcopenia.
Keywords: Myostatin, Sarcopenia, Muscle mass, Aging, Physical activity, Skeletal muscle mass.

INTELLECTUAL PROPERTY RIGHTS, GREEN INNOVATION, AND ENVIRONMENTAL SUSTAINABILITY: EVIDENCE FROM ASSAM AND NORTHEAST INDIA

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Abstract
Sustainable development requires innovation systems that balance economic growth with environmental sustainability, social welfare and inclusive development. Intellectual Property Rights (IPRs) beyond protecting inventions and creative works have become important tools for promoting technological innovation, entrepreneurship and sustainable resource use. This chapter examines the relationship between IPRs, green innovation and environmental welfare in the context of Assam and Northeast India through a qualitative analysis of secondary sources including academic literature, government reports, policy documents and international publications.
The chapter argues that effective IPR protection can support sustainable development by encouraging environmentally friendly technologies, strengthening Geographical Indication (GI)-based products, protecting indigenous knowledge and promoting green entrepreneurship. Drawing on innovation, environmental and welfare economics, it highlights how knowledge-based development contributes to ecological conservation, economic resilience and human well-being. Assam provides a significant case study because of its rich biodiversity, traditional knowledge, agricultural diversity and emerging innovation ecosystem. GI-recognised products such as Assam Tea, Muga Silk, Joha Rice and Boka Chaul illustrate how intellectual property protection can enhance local livelihoods while preserving cultural heritage and ecological resources. The study further reviews key policy initiatives, including India's National Intellectual Property Rights Policy, Start up India and the Assam Start-up and Innovation Policy 2025 which aim to foster innovation-led sustainable development. Despite these opportunities, challenges such as limited awareness of IPRs, inadequate institutional and research capacity restricted access to technology and weak market linkages continue to hinder progress. The chapter concludes that integrating intellectual property policy with green innovation and environmental governance is essential for achieving sustainable development, strengthening regional innovation systems and improving environmental welfare in Assam and Northeast India.
Keywords*:* Intellectual Property Rights; Green Innovation; Environmental Welfare; Sustainable Development; Assam

ASSESSMENT OF METALLIC ELEMENT CONTENT AND SAFETY OF MORINGA OLEIFERA GROWN IN ALGERIA

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ABSTRACT
Moringa oleifera is a plant widely recognized for its nutritional richness and its content of various mineral elements. However, the presence of certain metallic elements at high concentrations may represent a potential risk to the quality and safety of the plant. Therefore, this study aimed to characterize the metallic composition of *M. oleifera* by determining the concentrations of several elements, including Al, Cd, Cr, Co, Cu, Fe, Mn, Ni, Pb, Zn, and Ag. The results revealed the presence of several metallic elements, with iron showing the highest concentration (409 mg/kg), followed by aluminum and zinc (240 mg/kg each). Copper, manganese, chromium, cobalt, nickel, and lead were also detected, whereas cadmium and silver were below the detection limits. However, assessing the safety of these concentrations requires comparison with the applicable regulatory standards and permissible limits to determine whether the measured levels pose a potential health risk. These findings contribute to a better characterization of the mineral composition of *M. oleifera* and to the assessment of its quality for its various uses.
Keywords: *Moringa oleifera;* metallic elements; mineral composition; heavy metals; metal contamination; plant safety; toxicity.

REVOLUTIONIZING CANCER DIAGNOSIS: THE POTENTIAL OF 3D PRINTED NANOSENSORS

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ABSTRACT
Cancer is a complicated illness with a worldwide impact, requiring ongoing breakthroughs in diagnosis and treatment. The application of 3D printing technology is increasingly recognized as an innovative tool in cancer diagnosis, offering enormous possibilities in detection and surveillance. The study aims to improve early diagnosis and prognosis for patients. 3D printing has become more popular for producing precise, customizable nanosensors with high sensitivity and specificity. The study covers the latest advances in 3D-printed cancer nanosensors. It discusses how inkjet printing, stereolithography, and fused deposition modeling can create intricate nanostructures with increased performance. Design and functionalization strategies for targeting nucleic acids, proteins, and circulating tumor cells are also covered. Nanomaterial-based sensors can detect tumor biomarkers, circulating cells, and extracellular vesicles, improving cancer diagnosis and survival. Integrating 3D-printed nanosensors with fluorescence, electrochemical, and surface-enhanced Raman spectroscopy allows rapid and accurate cancer diagnosis in clinical settings. The publication critically reviews and synthesizes previous research to show how 3D-printed nanosensors could improve cancer diagnosis as well as personalized therapy. The study explores the capacity of 3D-printed nanosensors to bring about significant changes in the field of cancer diagnostics. Using 3D-printed technology and additive manufacturing, these sensors provide exceptional sensitivity and specificity for the early identification of cancer biomarkers. Their ability to be customized allows for specific therapies for various types of cancer, offering substantial progress in precision medicine. The paper analyzes the most recent advancements, obstacles, and potential future opportunities of 3D-printed nanosensors, with a specific focus on their significant impact on transforming cancer diagnosis.
Keywords: 3D printing, Nanosensor, Stereolithography, Cancer diagnosis, personalized therapy,

BIOCHEMISTRY OF TODAY, MEDICINE OF TOMORROW: INTRIGUING FACTS, FIGURES, AND MOLECULAR EVIDENCE FOR BIOCHEMISTRY AS THE FOUNDATION OF MODERN MEDICINE

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Abstract
Biochemistry stands at the molecular core of modern medicine, linking the chemistry of life with the diagnosis, prevention, and treatment of disease. This review presents biochemistry as a foundational discipline of medicine and traces how biochemical discoveries have progressed from basic descriptions of cellular processes to technologies that guide clinical decisions and therapeutic development. The review aims to demonstrate, through selected facts, figures, landmark discoveries, and molecular evidence, how biochemical knowledge shapes contemporary healthcare and how current advances may define the medicine of tomorrow. The review focuses on major biochemical processes and their medical applications, including enzyme function, intermediary metabolism, protein structure, nucleic acid biology, cell signalling, oxidative stress, molecular diagnostics, biomarkers, pharmacology, pharmacogenomics, omics technologies, drug discovery, and emerging molecular therapies. Particular attention is given to the transition from conventional diagnosis and treatment toward molecularly guided healthcare. Published evidence from biomedical and biochemical literature is used to highlight measurable links between biochemical discoveries and clinical practice, including the use of enzymes and metabolites as disease indicators, molecular targets in cancer therapy, genetic variation in drug response, and biomolecular information in precision medicine. The evidence reviewed shows that many routine medical decisions depend directly or indirectly on biochemical principles. Measurements of glucose, lipids, enzymes, electrolytes, hormones, metabolites, and disease-associated proteins provide information used in diagnosis, monitoring, and risk assessment. At the molecular level, knowledge of DNA, RNA, proteins, receptors, enzymes, and signalling pathways has enabled the development of targeted medicines and molecular diagnostics. Advances in genomics, transcriptomics, proteomics, metabolomics, and pharmacogenomics are further increasing the capacity to distinguish disease subtypes and predict therapeutic responses. In parallel, recombinant DNA technology, monoclonal antibodies, RNA-based medicines, gene therapies, and cell-based treatments demonstrate how biochemical knowledge can move from laboratory discovery to clinical intervention. The discussion also considers the growing role of artificial intelligence, computational biology, structural biology, and multi-omics integration in drug discovery and patient care. These developments are shifting medicine toward earlier detection, molecular classification, individualized treatment, and continuous monitoring. However, translation from biochemical discovery to clinical use requires rigorous validation, reproducibility, ethical oversight, affordability, and equitable access. Such progress also depends on collaboration among biochemists, clinicians, pharmacologists, molecular biologists, bioinformaticians, and biotechnology researchers. Overall, the reviewed evidence supports the view that biochemistry provides much of the molecular language through which modern medicine understands health and disease. Its principles underpin laboratory medicine, pharmacology, molecular pathology, biotechnology, and precision therapeutics. As medicine becomes increasingly molecular, advances in biochemistry are likely to remain central to the discovery of new biomarkers, therapeutic targets, diagnostic technologies, and treatment strategies. The future of medicine will therefore depend not only on new clinical approaches, but also on deeper understanding of the biochemical processes that sustain life and drive disease.
Keywords: Biochemistry; Molecular Medicine; Precision Medicine; Pharmacogenomics; Drug Discovery.

BAYESIAN COMPETING RISKS ANALYSIS USING FLEXIBLE HALF-LOGISTIC-G HAZARD MODELS

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Abstract
Competing risks arise frequently in biomedical and reliability studies when individuals or systems are exposed to multiple mutually exclusive failure mechanisms. Conventional exponential competing risks models assume constant cause-specific failure rates, which may inadequately capture complex and time-varying failure patterns. We propose a flexible Bayesian competing risks framework based on the Half-Logistic-G family and investigate its predictive performance relative to the standard exponential baseline. Three models are considered: Type I Half-Logistic Exponential (TIHL-E), Type II Half-Logistic Exponential (TIIHL-E), and Type II Half-Logistic Exponentiated Exponential (TIIEHL-E). Bayesian inference is performed using Hamiltonian Monte Carlo implemented in Stan. Model performance is assessed using both simulated data and a melanoma dataset with two competing causes of failure, employing LOOIC, WAIC, DIC, integrated Brier score (IBS), and time-dependent area under the receiver operating characteristic curve (AUC) at 1, 3, and 5 years.Among the competing models, TIHL-E consistently provides the most favorable predictive performance. For the simulated data, TIHL-E achieves an LOOIC of 2297.06 and an IBS of 0.121, while for the melanoma data, the corresponding values are 1448.30 and 0.118. Its discriminatory ability is also superior, with time-dependent AUC values of 0.842, 0.815, and 0.798 for the simulated data and 0.876, 0.851, and 0.823 for the melanoma data at 1, 3, and 5 years, respectively. In contrast, the exponential baseline yields substantially lower AUC values of 0.654, 0.632, and 0.611 for the simulated data and 0.612, 0.588, and 0.564 for the melanoma data. Calibration analysis further demonstrates close agreement between predicted and observed risks for TIHL-E, whereas the exponential model exhibits systematic miscalibration. Cause-specific analyses also reveal distinct temporal mortality patterns, with melanoma-related mortality being highest during the early follow-up period and subsequently declining, while mortality from other causes shows an increasing trend.
Overall, the findings demonstrate that the Bayesian TIHL-E model provides a flexible and predictive framework for competing risks analysis, offering substantial improvements in discrimination, calibration, and predictive accuracy over the conventional exponential baseline.
Keywords:Bayesian competing risks,Half-Logistic-G family, TIHL-E model,Survival analysis,Bayesian inference, Hamiltonian Monte Carlo,Stan,Predictive modeling,Time-dependent AUC,Integrated Brier score,Model comparison,Melanoma survival data

ARTIFICIAL INTELLIGENCE IN CLINICAL PRACTICE AND ITS FUTURE PERSPECTIVES

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Abstract
Artificial intelligence based medical technologies are increasingly moving from experimental research toward practical use in clinical care. Deep learning methods can process large and complex datasets generated by wearable devices smartphones and other mobile health monitoring technologies. These technologies have created new opportunities in several areas of medicine. Current clinical applications include the detection of atrial fibrillation epileptic seizures and hypoglycemia as well as disease diagnosis through medical imaging and histopathological analysis. The integration of artificial intelligence into healthcare may improve patient autonomy and support more personalized treatment. However, its adoption also presents challenges for physicians and healthcare institutions because many healthcare professionals have not been adequately prepared for the rapid development of digital medicine. The growing use of artificial intelligence also emphasizes the need for clinical validation of these technologies through appropriate trials. Medical education and training may need to be updated to address the changing requirements of digital healthcare. Ethical concerns related to continuous patient monitoring data use and connected healthcare systems also require careful consideration. This paper reviews recent scientific literature to examine the current role of artificial intelligence in clinical practice and discusses its benefits future opportunities and potential risks for physician's healthcare institutions medical education and bioethics.
Keywords: Artificial intelligence; Deep learning; Clinical practice; Digital healthcare; Medical ethics

1. Introduction

Artificial intelligence (AI) has become an increasingly important technology in modern healthcare and is being applied to tasks that traditionally require human intelligence. Machine learning (ML) enables computer algorithms to learn from data and improve their performance, while deep learning (DL) uses multilayer neural networks to identify complex patterns. Natural language processing (NLP) allows computers to understand and generate human language. These technologies support a wide range of healthcare applications, including automated medical image interpretation, clinical decision support, disease diagnosis, and robotic-assisted surgery (1,2). The growing availability of digital health information has further expanded the potential of AI in clinical practice, allowing intelligent systems to process and analyze large and complex datasets that would be difficult to evaluate manually.

The use of AI in medicine has developed over several decades. Early medical expert systems, such as INTERNIST-1, developed in 1971, and MYCIN, developed during the 1970s, were designed to assist physicians with diagnostic decision-making (2). AI subsequently progressed from rule-based expert systems toward statistical and neural network-based methods. This development has been supported by the rapid growth of electronic health records, genomic databases, wearable devices, smartphones, and Internet of Things (IoT) technologies.

These sources continuously generate large quantities of healthcare data, increasing the need for advanced analytical methods. Aamir et al. (3) highlighted that the growth of big data and IoT has increased the importance of AI and ML for analyzing healthcare information. In particular, the development of DL and ML has created new possibilities for identifying patterns in clinical data and supporting more individualized diagnosis and treatment.

In recent years, AI has increasingly moved from experimental research toward practical clinical applications. Bajwa et al. (4) described AI as a technology with the potential to transform medical practice and healthcare delivery by improving efficiency and diagnostic precision. Evidence from recent clinical research demonstrates this potential. A multicenter study of the deep learning ECG model EchoNext reported an accuracy of 77.3% for detecting structural heart disease from 12-lead ECGs, compared with a mean accuracy of 64.0% among cardiologists. The model achieved a sensitivity of 72.6% and specificity of 80.7%, while the corresponding values for cardiologists were 61.1% and 66.1%, respectively. The reader study involved 13 cardiologists evaluating 150 ECGs, providing a direct comparison between AI-based and human interpretation (5). AI systems have also demonstrated promising performance in areas such as radiology, dermatology, and pathology, where algorithms have performed at levels comparable to or exceeding those of human specialists in specific tasks (2). These developments indicate the potential of AI to support clinical decision-making, reduce routine workload, and contribute to improved healthcare outcomes and patient experiences.

Despite these developments, the integration of AI into clinical practice presents several challenges. Healthcare professionals need appropriate knowledge and training to work effectively with rapidly developing digital technologies, while AI-based systems require adequate clinical validation before widespread implementation. The increasing use of continuous patient monitoring and connected healthcare systems also raises concerns regarding the collection, management, and use of sensitive health data. In addition, medical education may need to adapt to prepare future healthcare professionals for increasingly technology-driven clinical environments. Therefore, the growing role of AI in medicine involves not only technological opportunities but also clinical, educational, institutional, and ethical considerations. This paper discusses the current role of AI in clinical practice and examines its major applications, potential benefits, future opportunities, and challenges, with particular attention to healthcare professionals, clinical validation, medical education, and bioethical issues.

2. **Development of AI in Clinical Practice**

Artificial intelligence has increasingly become integrated into clinical practice, particularly in medical imaging and digital pathology, where deep learning and neural network techniques can improve diagnostic accuracy, workflow efficiency, and prognostic assessment (6–8). In radiology, AI systems can analyze large imaging and clinical datasets, identify subtle visual patterns, support risk assessment, and assist treatment planning (8,9). Convolutional neural networks (CNNs) are particularly useful because they can automatically extract relevant features from medical images without requiring manual feature selection (9,10). For example, CNN-based systems such as Auto Lung Nodule Detection can identify and classify lung nodules, achieving a specificity of 83.2%, although its reported positive predictive value was 5.5% (11). AI can also automate routine image analysis and report generation and prioritize urgent cases, allowing radiologists to focus on clinically important findings (6,7,11). Computer-aided systems integrating fMRI, MRI, DTI, PET/CT, and MR spectroscopy can further support tumor localization, surgical planning, and the identification of biomarkers associated with neurodegenerative diseases (6,12).

AI has also produced important developments in pathology and oncology. Digital pathology allows AI systems to detect, segment, and analyze tumor cells from whole-slide images, supporting diagnosis, grading, and prognosis (13–15). CNN-based models trained on annotated prostate biopsy slides have achieved a ROC-AUC of approximately 0.99 for detecting neoplastic lesions, while AI tools such as Paige prostate and Galant prostate reported sensitivity of 97.7% and specificity of 99.3% across 1,876 prostate biopsies (14). AI can additionally assist with Gleason scoring, tumor measurement, and identification of invasion markers, while multimodal models combining pathological, clinical, and genomic information can improve prediction of survival, recurrence, and metastasis (14,15). Other architectures, including recurrent neural networks, long short-term memory networks, and generative adversarial networks, have been applied to sequential imaging, image synthesis, and segmentation,

although GAN-based systems may become unreliable when training datasets are limited (15,16,17). In dermatology, AI has demonstrated strong potential for skin lesion assessment and melanoma detection. One CNN trained on 12,378 dermoscopic images outperformed 136 of 157 dermatologists, achieving a mean sensitivity of 87.5% and specificity of 60% (19). AI has also been applied in ophthalmology, particularly diabetic retinopathy and age-related macular degeneration. The IDx-DR system reported 87.4% sensitivity and 89.5% specificity for diabetic retinopathy screening, while EyeArt 2.0 analyzed approximately 850,908 images from 101,710 patients and achieved sensitivity and specificity of 91.3% and 91.1%, respectively (20). These developments demonstrate how AI is expanding across multiple clinical specialties by supporting image interpretation, disease detection, triage, prognosis, and treatment planning while complementing rather than necessarily replacing healthcare professionals.

3. **Current Clinical Applications of AI**

AI is increasingly being used as a clinical decision-support tool by analyzing medical images, patient records, and other health information to assist physicians in diagnosis and treatment planning. For example, the FDA-approved IDx-DR system can detect more than mild diabetic retinopathy from retinal images, with reported sensitivity of 87% and specificity of 90% (4). AI has also demonstrated strong performance in radiology. A convolutional neural network trained by Stanford University using more than 112,120 chest X-rays from the National Institutes of Health dataset achieved an area under the curve (AUC) of 0.862 for detecting atelectasis, compared with 0.808 for radiologists (20). Similarly, a study involving 120,950 patients reported higher sensitivity for AI than physicians in breast cancer detection, with values of 0.85 and 0.77, respectively, while specificity was comparable between the two groups (21). AI can also support treatment planning by automatically identifying clinical target volumes in prostate cancer and detecting rectal cancer from endoanal ultrasound, where a CNN-based model achieved an AUC of 0.85 (22). Beyond diagnosis, AI-based symptom assessment tools can help patients determine the urgency of their condition and may support early identification of life-threatening conditions, allowing physicians to intervene more rapidly (23).

AI also has applications in therapeutic drug monitoring, risk prediction, and continuous patient monitoring. By considering factors such as genetics, age, weight, kidney and liver function, previous medical conditions, and concurrent medications, AI can help predict drug clearance and identify effective or potentially toxic medication doses (24,25). AI can additionally predict drug interactions and identify patients who may be more susceptible to adverse effects (26). Predictive models have been used to identify patients at risk of clinical deterioration, hospital readmission, or other adverse outcomes, potentially supporting earlier intervention and better resource allocation (27,35). However, these systems may also produce unintended consequences, including unnecessary admissions when subtle risks are detected too early or when clinicians become overly dependent on automated predictions (27). Concerns have also been raised about potential inequalities in predictive systems and limited transparency in how some risk assessments are generated, which can affect clinical trust (28). Combining electronic health records with patient-generated health data from wearable devices and mobile applications provides another opportunity for continuous monitoring and more individualized healthcare (29).

AI is further contributing to precision treatment through the integration of clinical, genomic, and patient-specific information. Machine learning can analyze genomic data to identify disease-associated patterns that may be difficult to recognize through conventional statistical methods (30–32). The combination of AI and genomic medicine has also created opportunities for drug discovery, drug repurposing, identification of new therapeutic targets, and prediction of potential toxicities such as cardiotoxicity and hepatotoxicity (33,34). Predictive models can use patients' medical histories, demographic characteristics, and lifestyle factors to identify individuals at higher risk of chronic diseases and support targeted preventive interventions (35). AI can also improve medication safety by identifying potentially inappropriate prescriptions. For example, one system detected 74% of risky prescriptions before medication was prescribed, while other research found that clinicians showed greater trust in AI-based medication recommendations when the system provided explanations for its decisions (37,38). AI-based dosing systems have also demonstrated potential for individualized treatment, including warfarin dose selection and chemotherapy adjustment through tools such as CURATE AI (39,40).

These applications demonstrate that AI is expanding beyond diagnosis toward continuous monitoring, risk prediction, medication safety, precision treatment, and individualized clinical decision-making, although effective implementation requires appropriate evaluation, transparency, ethical oversight, and stakeholder involvement (36).

4. **Benefits of AI in Healthcare**

AI can provide important benefits to healthcare systems facing increasing patient needs, complex medical conditions, and limitations in medical resources. By supporting clinical decision-making and automating routine activities, AI can improve productivity, clinical outcomes, and hospital workflows (41). One major benefit is improved diagnostic accuracy. AI can process large volumes of clinical information and identify subtle patterns that may be difficult to detect through conventional analysis. In radiology and pathology, AI has been reported to reduce diagnostic and workload time by approximately 90% for tasks such as lesion detection and identification of bone metastasis (42). AI can also support the early identification of conditions such as diabetic retinopathy, systemic infections, and cancer metastasis, allowing healthcare professionals to intervene more quickly (43). In addition, automated lesion detection, morphological assessment, and computerized image analysis can reduce routine workload and allow clinicians to concentrate on more complex decisions (42). However, the reliability of these benefits depends on the quality and representativeness of the data used to develop AI systems, as biased or low-quality data can produce misleading results (43,44).

AI can also improve healthcare workflows by automating administrative and routine activities. Language-based systems can assist in digitizing patient records and updating electronic health records, reducing paperwork and improving documentation. AI can also support staff scheduling according to workforce availability and patient-care requirements, with one study reporting a 12% reduction in extended-hour wages (45). AI-enabled virtual assistants can respond to routine patient inquiries, arrange consultations, and perform initial triage, allowing healthcare staff to devote more time to specialized clinical tasks (45,46). Another important benefit is the development of personalized medicine. AI can integrate clinical, genetic, and other patient-specific information to support individualized treatment planning rather than relying solely on generalized treatment strategies (41,43). AI systems can predict individual responses to medications, identify disease-related genetic variations, and support the development of targeted therapies (47). However, effective personalization depends on access to high-quality patient data, while informed consent and appropriate data privacy practices remain important for maintaining patient trust (46).

AI further contributes to early disease detection and prevention by analyzing large and diverse datasets to identify patterns and predict potential health risks (48). AI-based early-warning systems can analyze epidemiological, environmental, and online information to identify disease outbreaks more rapidly, while tools such as BlueDot have demonstrated the potential to identify early signals associated with emerging infectious diseases (48). AI can also predict risks such as hospital readmission and clinical deterioration and support community-level disease monitoring (45,47). Biosensors combined with AI enable continuous health monitoring and may facilitate early identification of chronic conditions such as diabetes and cardiovascular disease. In mental healthcare, AI-based systems can support screening and symptom monitoring, including the assessment of conditions through speech analysis (43). These capabilities can also assist healthcare systems in planning and allocating resources during public health emergencies (48).

Cost reduction and resource optimization represent another important benefit of AI. AI can automate administrative processes such as billing and insurance management, with estimates suggesting potential annual operational savings of up to $168 billion (49). AI can also support evidence-based clinical decisions by reducing unnecessary tests and procedures and improving the allocation of hospital resources such as beds and medical supplies. One reported application involved the completion of more than 45,000 tests within 45 days, demonstrating the potential of automated systems to process healthcare activities at scale (50). AI may also help identify financial irregularities and recover improperly allocated funds; IBM reported the recovery of more than $41.5 million in Medicaid funds through AI-supported analysis (43). Beyond direct financial benefits, AI is increasingly being used in medical education and professional development.

AI-based simulations can provide realistic clinical scenarios in controlled environments, allowing students and healthcare professionals to practice skills without placing patients at risk. In surgical education, AI can also provide immediate feedback on performance and skill development, helping connect theoretical knowledge with practical training (46,47). Thus, AI has the potential to improve healthcare through more accurate diagnosis, efficient workflows, personalized treatment, early detection, cost optimization, and improved medical education, while its effectiveness depends on responsible data management and appropriate implementation.

5. **Challenges and Ethical Considerations**

Despite the potential benefits of AI in healthcare, its clinical implementation presents important challenges related to data quality, bias, transparency, privacy, accountability, and professional responsibility. One of the major concerns is algorithmic bias because AI systems learn from existing datasets that may not adequately represent differences in sex, race, socioeconomic status, geography, or other population characteristics (51). For example, insufficient representation of African American patients in training data has been associated with inaccurate AI predictions, which may reduce clinicians' confidence in positive predictions for this population (52). AI can also reproduce historical patterns in healthcare and potentially reinforce existing inequalities (53,54). Predictive systems may similarly disadvantage patients from lower-income communities when social circumstances are interpreted as indicators of higher healthcare resource use (55). Regular auditing, disclosure of demographic characteristics in training datasets, and testing across different clinical settings are therefore important for identifying and reducing these biases (56).

Another major challenge is the limited interpretability of some AI systems. The complex processes through which certain algorithms generate predictions can make it difficult for physicians to understand why a particular recommendation has been produced, especially when it conflicts with clinical reasoning (57,58). Such "black box" behavior can reduce trust and make clinicians reluctant to incorporate AI into routine practice (59). Overreliance on AI may create an additional problem because excessive dependence on automated recommendations can weaken clinical reasoning and contribute to professional de-skilling (60). Therefore, AI should function as a support tool rather than eliminating meaningful human oversight. Clinicians should retain the ability to evaluate AI recommendations, override them when necessary, and make final decisions in high-risk situations (61,62).

Privacy, informed consent, and data security are also central ethical concerns because AI systems depend on large quantities of sensitive health information, including medical histories, demographic information, and genetic data (63,64). Patients should be informed when AI is involved in diagnosis or treatment and should understand its role, limitations, and potential risks (62,65). Appropriate safeguards include data de-identification, secure storage, access controls, continuous security monitoring, and compliance with relevant frameworks such as HIPAA and the General Data Protection Regulation (GDPR) (65,64). Privacy-preserving technologies such as federated learning can allow AI models to learn from decentralized datasets without directly sharing raw patient records (66). Transparency is similarly important because explainable AI, traceability, and auditability can help clinicians and patients understand automated decisions and support informed participation in healthcare (67,68).

Legal and regulatory uncertainty presents another challenge. Existing healthcare regulations were developed before the widespread adoption of modern AI technologies and may not clearly define responsibility when an AI-supported decision results in patient harm (69,70). Accountability may involve developers, healthcare professionals, institutions, or system maintainers, making clear multi-stakeholder responsibility frameworks necessary (65,71). AI systems must also be evaluated for safety and effectiveness across different populations and clinical environments before and after implementation. Regulatory differences between jurisdictions further complicate the deployment of AI-based medical technologies, while the absence of a universal framework can create inconsistencies in evaluation and oversight (72,73,74). In addition, integrating AI with existing hospital information systems can involve technical difficulties, high costs, privacy concerns, and usability problems, particularly because healthcare institutions often use different electronic systems (75). Frameworks such as DECIDE-AI emphasize phased clinical evaluation and shadow deployment to identify safety and bias-related problems before full implementation (66).

Overall, responsible use of AI in healthcare requires continuous clinical validation, representative data, informed consent, privacy protection, explainability, staff training, clear accountability, and meaningful human oversight.

6. **Conclusion**

Artificial intelligence has become an increasingly important component of contemporary clinical practice, with applications spanning diagnosis, treatment planning, surgery, cardiology, and clinical decision support. Deep learning and related technologies have improved medical image interpretation, lesion detection, and predictive analysis by processing large volumes of clinical data, while AI systems can automate routine activities, prioritize urgent cases, and improve clinical workflows. In surgery, AI-assisted planning, intraoperative navigation, and robotic systems can support greater precision and efficiency, while in cardiology, machine learning can enhance electrocardiographic and imaging interpretation, remote monitoring, and continuous patient assessment. Wearable devices and digital technologies, including smartwatches and digital stethoscopes, can further extend monitoring and virtual care to remote and underserved populations. Despite these benefits, important challenges remain, including data bias, limited interpretability, privacy, informed consent, accountability, regulatory uncertainty, excessive dependence on automated systems, and difficulties integrating AI into existing hospital infrastructures. Addressing these issues requires rigorous clinical validation, representative and equitable data, transparent development, appropriate training, effective governance, and meaningful human oversight. With responsible implementation and continued interdisciplinary collaboration, AI can contribute to more accurate, efficient, personalized, and patient-centered healthcare while maintaining the essential role of clinical expertise and professional judgment.

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ARTIFICIAL INTELLIGENCE FOR CANCER DIAGNOSIS AND PROGNOSIS

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Abstract
Cancer is a serious disease associated with high mortality and frequent recurrence. Its treatment often requires long term care and substantial financial resources. Early and accurate diagnosis together with reliable prognosis prediction is important for improving patient survival and treatment outcomes. Advances in statistics and computer engineering have enabled researchers to use computational approaches such as multivariate statistical analysis for cancer prognosis assessment. These approaches can provide more reliable predictions than traditional empirical methods. In recent years' artificial intelligence especially machine learning and deep learning has become increasingly important in cancer research and has improved the accuracy of disease diagnosis and prognosis prediction. This article reviews recent studies on the use of artificial intelligence for cancer diagnosis and prognosis and examines its major advantages. The review focuses on how artificial intelligence can support clinical decision making through highly accurate analysis of complex medical data. It also discusses how these technologies are contributing to advances in cancer research and clinical care. Finally, the major opportunities and challenges associated with the clinical implementation of artificial intelligence are considered. This review provides an updated perspective on the potential of artificial intelligence to improve cancer diagnosis and prognosis and support better healthcare outcomes.
Keywords: Artificial intelligence; Cancer diagnosis; Cancer prognosis; Machine learning; Deep learning

1. Introduction

Cancer is one of the major causes of death worldwide, creating a substantial burden for patients and healthcare systems. Despite advances in cancer screening and treatment, several unmet needs continue to affect clinical outcomes, quality of life, and healthcare efficiency [1,2]. Early detection is particularly important because diagnosis at an advanced stage can limit treatment options and worsen patient outcomes. However, insufficient access to screening and the absence of highly accurate biomarkers remain important barriers to timely diagnosis [3]. Current cancer treatment mainly includes chemotherapy, radiotherapy, and immunotherapy, but these treatments can produce serious adverse effects, including cardiotoxicity and neuropathy [4,5]. In addition, the increasing cost of cancer care creates a further burden, while advanced targeted and immunotherapies may not be equally accessible to all patients [6,7]. Another major challenge is tumor heterogeneity, as differences in tumor characteristics can lead to substantial variation in treatment response between patients [8,9]. Conventional imaging and biomarker-based diagnostic methods also have limitations in sensitivity and specificity and may provide an incomplete representation of changing tumor characteristics during disease progression [10,11].

Artificial intelligence (AI) has therefore gained increasing attention as a tool for addressing complex problems in cancer medicine [12]. AI refers to computational systems capable of performing tasks that normally require aspects of human intelligence, including pattern recognition and data interpretation [13].

Within AI, machine learning (ML) uses statistical and computational techniques to identify patterns from data, while deep learning (DL) and other algorithms have expanded the ability to analyze complex medical information [14–16]. These developments have particular relevance to oncology because cancer diagnosis and treatment generate large volumes of imaging, clinical, pathological, and molecular data. AI-based image analysis can support the detection and classification of tumors and assist radiologists and pathologists in interpreting complex diagnostic information [17,18]. Beyond diagnosis, AI can combine patient history, genetic profiles, and tumor characteristics to support individualized treatment decisions and estimate how a patient may respond to a particular therapy [19,20]. AI can also contribute to clinical trial matching and treatment optimization, while post-treatment monitoring systems may help identify complications or potential recurrence earlier [21–23].

The application of AI in cancer care, however, is not without limitations. Many developed models remain at the research stage and require appropriate clinical validation before routine use in patient care [24,25]. AI performance is also closely dependent on the availability of high-quality and appropriately annotated patient data, meaning that incomplete or poorly representative datasets can affect model reliability [26]. In clinical practice, additional concerns involve patient privacy, informed consent, regulatory requirements, infrastructure, implementation costs, and the availability of professionals with relevant AI expertise [27–32]. Lack of understanding of how AI systems generate their outputs may also contribute to hesitation among clinicians, particularly when decisions have direct consequences for patients [30,31]. Moreover, AI should not be considered a replacement for clinical expertise, since treatment decisions also require consideration of individual patient circumstances that may not be fully represented in computational data [33]. Therefore, the role of AI in oncology is better considered in terms of supporting cancer diagnosis, prognosis assessment, treatment planning, and patient monitoring. This paper examines these applications while discussing the limitations and future considerations surrounding the clinical use of AI in cancer care.

2. AI Foundations for Oncology: Beyond Algorithms

Machine learning (ML) forms a core component of AI-based oncology by learning patterns from clinical and biomedical datasets rather than relying on predefined rules. In cancer research, ML is used for image-based diagnosis, outcome prediction, and individualized treatment decisions. The learning process depends on the type and availability of training data. Supervised learning requires labeled datasets and is commonly used for cancer image classification, whereas self-supervised learning derives useful representations from unlabeled data and can reduce the extensive expert annotation required for medical datasets. Reinforcement learning follows a different mechanism in which an agent learns through rewards and penalties while interacting with an environment, making it relevant to sequential and changing decision-making problems [34,35,36,37]. These three paradigms and their learning processes are illustrated in Figure 2.

Deep learning (DL) extends ML through multiple layers of interconnected computational units that learn increasingly complex features. Convolutional neural networks (CNNs) are particularly suitable for cancer imaging because their convolution and pooling operations capture spatial and morphological characteristics of tumors. Transformers use self-attention to identify relationships within complex sequences and have been applied to genomic information and clinical records, supporting prognosis and treatment-related prediction. Generative adversarial networks (GANs) use a generator and discriminator to produce synthetic data and can help augment datasets when images from rare cancer types are limited [38,39,40]. Thus, the choice of architecture depends strongly on the nature of the oncology data and the clinical task rather than on the use of a single universal AI model.

The practical deployment of these models also requires solutions for distributed data and patient privacy. Federated learning allows several healthcare institutions to collaboratively train a model while keeping patient data within their respective systems; model updates are exchanged instead of the original clinical records. Edge computing complements this strategy by processing data closer to where they are generated, reducing dependence on centralized cloud infrastructure and improving processing latency [41,42]. Another important development is multimodal data fusion, which combines complementary information from medical imaging, multiomics, laboratory measurements, electronic health records, and other clinical sources. This integration can provide a more complete representation of tumor characteristics and support cancer classification, treatment-response assessment, and prognosis [43].

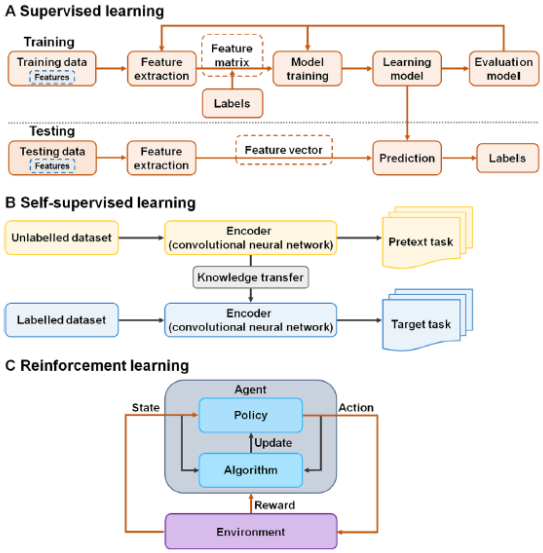


Figure 2. Supervised, self-supervised, and reinforcement learning models.

3. AI-Powered Cancer Diagnosis and Molecular Profiling

AI-based cancer diagnosis is being developed to address limitations in conventional diagnostic practice, including difficulty detecting small or deeply located tumors, distinguishing tumor types, variability in expert interpretation, and the time and accessibility constraints of some diagnostic procedures [44–48]. AI can analyze large volumes of imaging, pathological, and clinical data and identify patterns that support tumor detection and classification. Current applications mainly involve oncological imaging, digital pathology, and multimodal integration of molecular and clinical information [49].

Oncological imaging represents one of the most extensively investigated applications of AI in cancer diagnosis. Deep learning and other ML models have been applied to CT, MRI, and PET images for cancer screening, early detection, and tumor classification. The studies summarized in Table 1 cover breast, colorectal, esophageal, lung, gastric, hepatocellular, ovarian, pancreatic, prostate, glioma, and lymphoma cancers. Lung cancer has received particularly extensive investigation, with models using CT images, clinical information, radiological features, and genomic data. Reported results include an AUC of 0.98 for early detection using low-dose CT [50], 98.17% accuracy with a densely connected CNN for lung cancer detection [51], and an AUC of 0.890 in internal and 0.843 in external testing for a multimodal model combining CT images with pulmonary nodule characteristics [52]. Similar applications have been reported for other cancers. For example, a deep learning model for gastric cancer screening achieved an AUC of 0.98, while a CNN for pancreatic cancer detection reported an AUC of 0.99 with 97% sensitivity and 100% specificity [53,54]. These findings demonstrate the ability of AI models to extract diagnostic information from imaging data across different cancer types.

MRI provides another important source of information because of its detailed visualization of soft tissues. AI-based models have been investigated for breast cancer, glioma, intrahepatic cholangiocarcinoma, lung cancer, and prostate cancer. A CNN and vision-transformer-based model for glioma detection achieved accuracies of 98.4% and 99.3% on two separate datasets, while a deep learning model for intrahepatic cholangiocarcinoma achieved an AUC of 0.994 in the training cohort and 0.937 in the test cohort [55,56]. PET-based AI applications have also been explored for lymphoma and lung cancer, including tumor identification and improvement of PET image quality [57–61]. Together, these applications show how AI can be incorporated into different imaging modalities rather than being restricted to a single diagnostic technique.

Digital pathology extends AI-based diagnosis from radiological images to microscopic tissue assessment.

Pathological examination remains essential for confirming cancer, determining tumor type, and assessing grade, while digital pathology enables high-resolution tissue slides to be analyzed computationally [62–64]. Several AI tools have demonstrated strong performance in breast cancer pathology.

Ibex Galen Breast HER2 achieved an AUC of 0.997 for breast biopsy analysis, while Mindpeak Breast reported AUC values of 0.99 for invasive carcinoma and 0.98 for ductal carcinoma in situ [65,66]. Other systems, including Paige Breast Suite, PathAI: AIM-HER2, and Visiopharm, have been used for tumor detection, biomarker assessment, and metastasis-related analysis [67–69]. Paige Prostate has also been applied to prostate biopsy assessment and was associated with reductions in immunohistochemistry studies, second-opinion requests, and reporting time [70]. AI-supported endoscopic and dermatological image analysis has further expanded these applications to gastrointestinal and skin cancers [71,72].

Cancer diagnosis can be further improved by combining information from multiple biological and clinical sources. Multimodal data fusion integrates medical images with pathological, genomic, transcriptomic, proteomic, and clinical data, allowing complementary characteristics of a tumor to be evaluated together [73,74]. Studies summarized in Table 1 and the source literature have applied multimodal models to breast, glioma, lung, oral, hepatocellular, and bladder cancers [75–82]. In lung cancer, for example, combining CT images with morphological characteristics produced an internal AUC of 0.890 and an external AUC of 0.843 [52]. Such integration can provide information that may not be available from a single data type and can support more detailed tumor classification and treatment-related decisions. However, differences in data formats and quality, feature-fusion strategies, and model architecture remain important considerations when developing multimodal diagnostic systems [83].

Table 1. Selected applications of AI in cancer diagnosis using oncological imaging and digital pathology.

Clinical application	Cancer type	AI method	Diagnostic task	Reported performance	Ref.
Oncological imaging	Breast cancer	Deep learning	Screening from digital mammography and dedicated cone-beam breast CT	Interquartile range: 0.187; p = 0.862	[50]
Oncological imaging	Breast cancer	Deep learning	Diagnosis using the Wisconsin Breast Cancer Dataset	Recall: 98.7%; F1-score: 99.03%; accuracy: 99%	[51]
Oncological imaging	Colorectal cancer	Faster R-CNN	Detection of lesions from CT colonography	Sensitivity: 0.815 for lesions ≥6 mm; 0.738 for 6–10 mm; 0.883 for ≥10 mm	[52]
Oncological imaging	Esophageal cancer	CNN	Classification of cancerous and noncancerous CT images	Accuracy: 84.2%; F1-score: 0.742; sensitivity: 71.7%; specificity: 90.0%	[53]
Oncological imaging	Lung cancer	3D CNN	Screening from CT images	Reduced exposure risk of patient health information	[54]
Oncological imaging	Lung cancer	Deep learning	Early detection using 3D CT images	Accuracy: 95.9%	[55]
Oncological imaging	Lung cancer	Deep learning	Screening using CT images with clinical information	AUC: 0.8021	[56]
Oncological imaging	Lung cancer	Transfer learning	Detection from chest CT images	Accuracy: 91%; precision: 92%; recall: 91%; F1-score: 91.3%	[57]

Oncological imaging	Lung cancer	Deep learning	Screening with CT images and assessment of bone mineral density	Accuracy comparable to manual measurement	[58]
Oncological imaging	Lung cancer	Dense CNN	Detection from lung CT images	Accuracy: 98.17%; specificity: 97.32%; precision: 97.46%; recall: 97.89%	[59]
Oncological imaging	Lung cancer	ML and DL	Early screening using radiological, clinical, and genomic information	AUC: 0.587–0.910	[60]
Oncological imaging	Lung cancer	Deep learning	Screening using lung imaging and clinical metadata	AUC: 0.88	[61]
Oncological imaging	Lung cancer	Multimodal integrated feature neural network	Diagnosis from CT images and pulmonary nodule morphology	Internal AUC: 0.890; external AUC: 0.843	[62]
Oncological imaging	Lung cancer	3D CNNs	Early detection from lung CT images	AUC: 0.801 for 3D-CNN; 0.802 for MobileNet v2; 0.755 for EfficientNet-B0; 0.833 for SEResNet18	[63]
Oncological imaging	Lung cancer	Deep learning	Screening using CT images	AUC: 0.8719	[64]
Oncological imaging	Lung cancer	Deep learning	Early detection from single low-dose CT scans	AUC: 0.98	[65]
Oncological imaging	Lung cancer	Deep learning	Screening with low-dose CT	AUC: 0.89 ± 0.02	[66]
Oncological imaging	Lung cancer	ML	Screening using modified CT and serological indices	AUC: 0.931 validation; 0.99 test; accuracy: 0.857 validation and 0.955 test	[67]
Oncological imaging	Lung cancer	Deep learning	Early detection using low-dose CT	AUC: 0.827 ± 0.028	[68]
Oncological imaging	Lung cancer	Deep neural network	Early detection from lung nodule datasets	Accuracy: 98.2%	[69]
Oncological imaging	Lung cancer	ML	Early detection from lung CT images	Accuracy: 98.21%; precision: 98.71%; recall: 97.46%	[70]
Oncological imaging	Lung cancer	CNN	Early detection using CT images	Accuracy: 97.56%; specificity: 98.4%	[71]
Oncological imaging	Lung cancer	Deep learning	Early detection using CT images	Accuracy: 93.4%; sensitivity: 90.2%; AUC: 0.941	[72]
Oncological imaging	Lung cancer	Deep learning	Diagnosis using CT images	AUC: 0.9711	[73]

Oncological imaging	Lung cancer	DL, IoT, and CNN	Early diagnosis using CT images and sensor data	Accuracy: 98.85%	[74]
Oncological imaging	Lung cancer	CNN	Diagnosis from CT images	Accuracy: 93.25%; sensitivity: 89.22%; specificity: 95.82%; precision: 92.46%; F1-score: 0.9114; AUC: 0.9629	[75]
Oncological imaging	Lung cancer	Deep learning	Early detection using chest X-ray and CT images	Accuracy: 90%; sensitivity: 57.6%	[76]
Oncological imaging	Lung cancer	Deep learning	Screening with low-dose CT	Effective noise reduction while retaining image details	[77]
Oncological imaging	Lung cancer	Deep learning	Screening using CT images and metadata	Effective differentiation of malignant and benign cases using combined slice thickness ≥2.5 mm	[78]
Oncological imaging	Lung cancer	Deep learning	Detection from CT and chest radiography	AUC: 0.92; sensitivity: 94%; specificity: 73%	[79]
Oncological imaging	Gastric cancer	Deep learning	Automated screening using CT images	AUC: 0.98; accuracy: 93%; sensitivity: 92%; specificity: 92%; F1-score: 0.93	[80]
Oncological imaging	Hepatocellular carcinoma	Deep learning	Detection using noncontrast CT	AUC: 0.807 internal validation; 0.789 external testing	[81]
Oncological imaging	Hepatocellular carcinoma	Deep learning	Detection using CT images	Precision: 0.97216; recall: 0.919; accuracy: 95.35%; specificity: 95.83%; sensitivity: 94.74%	[82]
Oncological imaging	Ovarian cancer	Deep learning	Automated diagnosis	Accuracy: 98.43%	[83]
Oncological imaging	Pancreatic ductal adenocarcinoma	Reinforcement learning and DNN	Early cancer detection	Mean detection error, Hausdorff distance, and RMSE: 2.2, 4.9, and 2.6 mm, respectively	[84]
Oncological imaging	Pancreatic ductal adenocarcinoma	GAN	Cancer diagnosis	AUC: 0.79; precision-recall AUC: 0.87; accuracy: 0.67	[85]
Oncological imaging	Pancreatic cancer	Deep learning	Large-scale cancer detection	Accuracy: 0.907 ± 0.01; sensitivity: 0.905 ± 0.01;	[86]

				specificity: 0.908 ± 0.02; AUC: 0.903 ± 0.01	
Oncological imaging	Pancreatic cancer	Deep learning	Early cancer detection	AUC: 0.98; sensitivity: 0.94	[87]
Oncological imaging	Pancreatic cancer	CNN	Cancer detection	Sensitivity: 0.97; specificity: 1.00; AUC: 0.99	[88]
Oncological imaging	Pancreatic cancer	CNN, Vision Transformer, KNN, SVM, RF, XGBoost	Cancer diagnosis	Accuracy: 97.33%; F1-score: 96.25%	[89]
Oncological imaging	Pancreatic cancer	CNN	Cancer diagnosis	Accuracy: 99.64%	[90]
Oncological imaging	Breast cancer	Faster R-CNN	Detection from breast MRI	Accuracy: 94.46%	[91]
Oncological imaging	Breast cancer	Deep learning	Detection using dynamic contrast-enhanced MRI	Dice: 0.9468; Jaccard: 0.8990	[92]
Oncological imaging	Glioma	CNN	Diagnosis from MRI	Accuracy: 87%	[93]
Oncological imaging	Glioma	CNN, Vision Transformer, and explainable AI	Detection using MRI	Accuracy: 98.4% and 99.3% on two datasets	[94]
Oncological imaging	Intrahepatic cholangiocarcinoma	Deep learning	Diagnosis using CT and MRI	AUC: 0.994 training; 0.937 testing	[95]
Oncological imaging	Lung cancer	Deep learning	Screening using pulmonary MRI	Detection rate: ≥96.8%	[96]
Oncological imaging	Prostate cancer	Deep learning	Detection from anisotropic bi-parametric MRI	AP: 0.690; AUC: 0.909	[97]
Oncological imaging	Prostate cancer	SVM, XGBoost, and deep learning	Identification using bi-parametric MRI and clinical variables	AUC: 0.986 training; 0.965 testing	[98]
Oncological imaging	Prostate cancer	Deep learning	Detection from noncontrast MRI	Similarity scores: 0.69, 0.71, and 0.82; high reader agreement for PI-RADS scores	[99]
Oncological imaging	Prostate cancer	Deep learning	Detection using clinical information and prostate MRI	PPV: 58%; specificity: 44%; sensitivity: 96%; AUC: 0.79	[100]
Oncological imaging	Prostate cancer	ML models including XGBoost, RF, NN, and logistic regression	Early detection from MRI and clinical data	Specificity: 0.640, 0.638, 0.634, and 0.620	[101]

Oncological imaging	Lymphoma	Deep learning	Diagnosis using PET images	PET image quality improved with twofold acceleration	[102]
Oncological imaging	T-cell lymphoma	Logistic regression	Screening using 18F-FDG PET/CT	Accuracy: 0.779; AUC: 0.863	[103]
Oncological imaging	Lung cancer	Fully convolutional network	Diagnosis using PET images	Good diagnostic performance with reduced processing time	[104]
Oncological imaging	Lung cancer	Adaptive dilated CNN and hybrid attention-based DL	Detection using PET/CT images	Improved effectiveness compared with conventional detection methods	[105]
Oncological imaging	Follicular lymphoma	DL and ML	Identification using PET/CT radiomic features	AUC: 0.820	[106]
Digital pathology	Breast cancer	Paige Breast Suite	Detection from histopathological images	Diagnostic assistance with improved accuracy and effectiveness	[107]
Digital pathology	Breast cancer	Ibex Galen Breast HER2	Detection from breast biopsy images	AUC: 0.997	[108]
Digital pathology	Breast cancer	Mindpeak Breast	Detection from breast biopsy images	AUC: 0.99 for invasive carcinoma; 0.98 for ductal carcinoma in situ	[109]
Digital pathology	Breast cancer	PathAI: AIM-HER2	Detection from histopathological images	Improved diagnostic precision and workflow efficiency	[110]
Digital pathology	Breast cancer	Visiopharm	Detection of metastasis from histopathological images	Sensitivity: 100%; specificity: 41.5%; PPV: 29.5%	[111]
Digital pathology	Prostate cancer	Paige Prostate	Diagnosis from prostate biopsy images	Maintained high diagnostic accuracy while reducing IHC studies, second opinions, and reporting time	[112]
Digital pathology	Gastric cancer	CNN	Cancer diagnosis from gastrointestinal endoscopic images	Improved diagnostic accuracy and efficiency	[113]
Digital pathology	Skin cancer	DermAI	Early detection from dermoscopic images	Mean accuracy: 99.60%	[114]

4. Translational Evidence: From Bench to Real-World Impact

The translation of AI from experimental development to clinical oncology depends on whether models can maintain their performance when applied to real patient data and routine workflows. Real-world studies have already evaluated AI for mammographic breast cancer screening, MRI-based brain tumor detection, dermoscopic assessment of skin cancer, and histopathological identification of colon cancer [115–119].

Beyond detection, AI models have been used for automated cancer classification, clinical decision support, symptom management, treatment-response prediction, and prognosis assessment. Image-based systems can also reduce the workload associated with screening while maintaining control over false-positive findings [120–127]. These applications indicate that clinical value depends not only on diagnostic accuracy but also on whether AI can support existing oncology workflows.

Different AI models have distinct translational strengths and limitations. ChatGPT-based systems can assist with text-oriented tasks and improve consistency in pathology-related workflows, but their usefulness is limited when diagnostic decisions depend directly on medical images or other nontextual information [128]. CNNs have demonstrated strong performance in image-based cancer analysis, although their effectiveness depends on sufficient training data and may decline when images contain overlapping features. Ensemble learning combines predictions from multiple models and can compensate for weaknesses of individual algorithms, but this advantage comes with greater computational requirements and reduced interpretability [129]. Model selection therefore needs to reflect the type of clinical data and the intended diagnostic or predictive task.

Preclinical validation provides an important bridge between algorithm development and clinical testing. AIEgen-Deep, for example, was developed to distinguish cancer cells from healthy cells based on cellular morphology, while semantic segmentation models demonstrated high sensitivity and specificity for detecting head and neck tumors from multimodal data [130,131]. Other preclinical applications include machine-learning detection and quantification of brain metastases, assessment of breast cancer progression using photoacoustic spectroscopy, and prediction of chemotherapy sensitivity in pancreatic ductal adenocarcinoma using the transcriptome-based Pancreas-View model [132–134]. AI models have also been applied to circulating biomarkers to predict metastatic outcomes following neoadjuvant treatment in breast cancer models [135]. Such studies are useful for identifying model limitations and potential treatment failures before clinical implementation.

Clinical trials provide a more direct assessment of whether these systems can improve cancer detection and decision-making in patients. Randomized controlled trials have evaluated AI-assisted endoscopic systems for adenoma and esophageal cancer detection, while MRI-based AI tools have been investigated for glioma, breast cancer, and prostate cancer [136–147]. AI-supported dermoscopic analysis has also been evaluated as a clinical decision-support method for melanoma detection [148]. However, positive algorithmic performance does not automatically translate into improved clinical outcomes. Some evaluated AI systems did not improve cancer detection, emphasizing the need for external validation, robustness testing, and assessment across different patient populations and clinical environments before routine adoption [149–151].

AI has also moved beyond initial diagnosis toward monitoring disease progression. For example, PCMM-Net integrates clinical and radiological features to predict lymphovascular invasion in breast cancer [152]. These translational applications demonstrate how AI can connect imaging, pathology, and clinical variables to clinically relevant outcomes. Nevertheless, implementation requires high-quality datasets, transparent model behavior, protection of patient information, and evidence that clinicians and patients can use and trust AI-supported decisions. Addressing these issues is necessary for moving AI systems from technically successful models to reliable components of routine cancer care [153].

5. Challenges and Future Directions

The clinical use of AI in oncology is constrained by limited high-quality data and algorithmic bias. Obtaining sufficiently large and well-labeled datasets is particularly difficult for rare cancers, while limited sample diversity can reduce model generalizability when systems are applied to populations or clinical settings that differ from the training data [154,155]. Bias may also arise from patient selection, data collection, feature selection, or model design. A model developed mainly from one population may therefore perform differently in another population [156–158]. Future development should prioritize larger and more diverse datasets and robust validation across different patient groups and institutions. Recent oncology literature similarly identifies data diversity, bias, and external validation as major requirements for equitable AI implementation.

Clinical integration presents a separate set of challenges. AI systems need to fit existing hospital workflows, electronic systems, and multidisciplinary decision-making processes without creating additional operational burden [159]. Physician acceptance is also important because AI outputs may

influence diagnosis and treatment decisions. Concerns regarding reliability, missed clinical information, and excessive dependence on automated recommendations can affect adoption [25,33].

Training programs that improve clinicians' understanding of AI capabilities and limitations can support more effective human-AI collaboration [160]. Therefore, successful implementation requires not only technical performance but also compatibility with clinical practice and appropriate professional oversight.

Transparency, privacy, and accountability remain major ethical and regulatory concerns. Many DL models function as complex systems whose predictions are difficult to explain, creating problems when clinicians need to understand the basis of an AI-generated recommendation [161,162]. Explainable AI (XAI) can provide information about the features or processes contributing to a prediction and may help clinicians assess model outputs [163]. GPT-based systems have also been proposed as tools for explaining complex AI models, although the quality of such explanations depends on the underlying training data and model characteristics [164,165]. At the same time, cancer datasets contain highly sensitive patient information, making secure data collection, storage, and processing essential [166]. Representativeness is equally important because biased datasets can produce unequal performance across patient populations [167,168]. Clear responsibility for errors or missed diagnoses is another unresolved issue, particularly when decisions involve both AI systems and healthcare professionals [169,170].

Future development is increasingly focused on methods that provide more transparent and clinically meaningful AI. Causal inference may help distinguish relationships that are merely correlated from those that may contribute directly to cancer development, progression, or treatment response [171,172]. This could support biomarker discovery and evaluation of treatment effects. XAI can complement these methods by providing clinicians with interpretable information about model predictions [173,174]. However, causal analysis requires reliable and sufficiently large datasets, while increasing model interpretability without compromising predictive performance remains difficult [175,176].

International collaboration is another important direction for clinical translation. Transnational research networks can facilitate the sharing of data, technologies, and clinical experience and allow AI systems to be evaluated across populations with different genetic, environmental, and lifestyle characteristics [177–179]. Multicenter validation can also identify differences in model performance that may not be apparent in single-center studies. Greater harmonization of technical standards, ethical requirements, and regulatory practices could support more consistent deployment of AI across healthcare systems [178,180]. Education through international training programs, conferences, and collaborative initiatives can further improve AI literacy among clinicians and researchers [181,182].

Equitable implementation requires attention to infrastructure and access in addition to algorithmic performance. Healthcare institutions in resource-limited settings may require investment in computational infrastructure, technical support, and professional training before AI systems can be implemented effectively [183,184]. Regulatory oversight should address transparency, fairness, and potential disparities in AI-assisted diagnosis, while medical professionals need training to understand both the capabilities and limitations of these systems [185,186]. Developing representative datasets and supporting research involving underserved and low-income populations can further reduce the risk that AI-driven cancer care benefits only populations already well represented in clinical datasets [187,188].

6. Conclusion

AI is increasingly being applied across cancer diagnosis, molecular profiling, treatment prediction, and clinical decision support, with evidence of improved performance in several imaging, pathology, and multimodal applications. However, its wider clinical integration remains dependent on the availability of high-quality and diverse datasets, since limited or unrepresentative data can reduce model generalizability. The interpretability of complex AI systems also requires further attention so that clinicians can understand and appropriately assess model-generated recommendations. In addition, patient privacy, data security, algorithmic bias, and accountability must be addressed alongside technical development. Future progress therefore requires more robust algorithms, broader data collaboration, transparent and interpretable models, and appropriate ethical and regulatory frameworks to support the reliable integration of AI into clinical oncology.

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ARTIFICIAL INTELLIGENCE AND ITS IMPACT ON BUSINESS AND SOCIETY

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Abstract
The rapid development of intelligent products and services has increased the commercial availability of artificial intelligence and its influence on society and the global economy. This development has raised questions about whether the current growth of artificial intelligence represents a temporary trend or a technology capable of creating lasting global transformation. This paper examines the broad implications of artificial intelligence and considers both its positive and negative effects on governments community's businesses and individuals. The study explores the development of artificial intelligence from research and innovation to practical implementation. It also examines major academic achievements and technological innovations and their influence on entrepreneurship and global markets. In addition, the study investigates the factors that have contributed to the rapid advancement of artificial intelligence. Entrepreneurial activity in the artificial intelligence sector is examined using two lists of the top 100 artificial intelligence startups. The findings provide a broader understanding of technological innovation and the effects of artificial intelligence on businesses and society. The study also highlights how artificial intelligence may reshape business operations and contribute to changes in the global economy.
Keywords: Artificial intelligence; Technological innovation; Entrepreneurship; Business transformation; Global economy

1. Introduction

Rapid advances in digital technologies have significantly changed how businesses operate, make decisions, and interact with customers. Artificial intelligence (AI), big data, and the Internet of Things (IoT) have increasingly developed as interconnected technologies that enable organizations to automate activities, process large volumes of information, and improve the speed of business processes. Advances in AI, machine learning, and natural language interfaces have also expanded the range of knowledge-based tasks that can be performed by machines, including activities that were previously considered difficult to automate (Manyika et al., 2013). At the same time, IoT devices continuously collect information from physical environments, while AI systems can process and analyze these data to generate insights that support business decisions (Chui et al., 2010; Mayer-Schönberger & Cukier, 2013).

The growing capabilities of AI have created applications across a wide range of industries. AI-enabled systems and robots have been introduced into manufacturing, retail, banking, healthcare, finance, and customer service. For example, IBM Watson demonstrated the potential of AI to process large volumes of medical information and assist healthcare professionals in diagnosis and treatment decisions (Kaplan, 2015). Similarly, advances in machine perception have enabled systems such as Google's DeepMind to perform specialized tasks that previously required human capabilities (Chui et al., 2017). In financial markets, automated trading systems have also become an important component of market activity (Ford, 2015). These developments illustrate how AI is moving beyond experimental research toward practical applications that can influence organizational processes, products, and services.

The economic implications of these technologies are equally significant. Earlier studies identified substantial economic potential from the convergence of connected machines, data, and analytics. For example, GE estimated that the integration of machines, data, and analytics could develop into a major global industry, while McKinsey estimated that the Internet of Things could generate trillions of dollars in annual economic value by 2025 (Triple Pundit, 2015; Manyika et al., 2015). Such projections demonstrate the scale of economic expectations surrounding intelligent and connected technologies. However, the effects of AI extend beyond productivity and economic growth. Increasing automation may also alter employment patterns as organizations replace or restructure tasks previously performed by human workers. McKinsey estimated that technologies available at the time could automate a substantial proportion of paid work activities, with many occupations containing activities that could potentially be automated (Chui et al., 2016).

The increasing adoption of automation has also changed the economic considerations surrounding human labor and machines. Human workers generally involve continuing operational expenses, including salaries and benefits, whereas automated systems require greater initial investment but can operate with comparatively lower ongoing labor costs. As the cost of robotic and AI technologies declines, organizations may have greater economic incentives to automate selected activities (Ross, 2016). Earlier analysis by the Boston Consulting Group similarly projected that industrial robots could produce considerable reductions in labor costs in several major economies (Boston Consulting Group, 2015). These changes suggest that AI may influence not only individual jobs but also organizational structures, workforce requirements, and managerial practices.

Several technological and economic factors have contributed to the rapid development of AI. The maturation of machine learning, the emergence of deep learning, increased access to cloud computing, the availability of large-scale digital data, and improvements in hardware have substantially increased the performance and accessibility of AI systems. Deep learning, in particular, has improved the ability of artificial neural networks to perform complex information-processing tasks, while growing markets for data-driven products have created additional economic incentives for AI development (Stanford University, 2016). Consequently, organizations increasingly need to understand how these technologies can be integrated into business processes while ensuring that their use remains aligned with organizational objectives.

Against this background, this paper examines the broader impact of artificial intelligence on business and society. It discusses the development of AI from research and technological innovation to practical applications and considers its positive and negative implications for businesses, individuals, communities, and governments. The paper also explores the factors driving the rapid advancement of AI and examines entrepreneurial activity in the AI sector through an analysis of two lists of the top 100 AI startups. By connecting technological development, business transformation, entrepreneurship, and societal effects, the study provides a broader perspective on the role of AI in shaping contemporary organizations and the global economy.

2. Evolution and Development of Artificial Intelligence

The development of artificial intelligence can be divided into several major stages. From 1900 to 1950, foundational ideas in mathematics and computing established the basis for AI research. AI emerged as a distinct field between 1950 and 1956, followed by rapid development during the 1957–1973 AI revolution. Limited computing power and technological challenges led to the first AI winter from 1974 to 1980. Another period of growth, known as the AI boom, occurred from 1980 to 1987, followed by stagnation between 1987 and 1993. From 1993 to 2011, AI agents and machine learning technologies developed further. Since 2011, advances in deep learning, large datasets, and computing power have accelerated AI development and expanded its applications in business and society. Current research is also increasingly focused on artificial general intelligence, which aims to develop systems capable of performing a broad range of intellectual tasks. The major stages in the evolution of AI are presented in Figure 1.

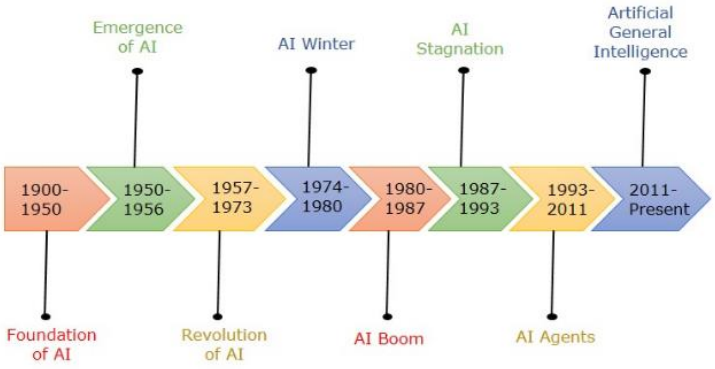


Figure 1. Evolution of Artificial Intelligence.

3. Artificial Intelligence in Business

Artificial intelligence and automation are transforming business operations by improving efficiency, reducing costs, and supporting faster decision-making. Automation can create value beyond simply replacing human labor by helping organizations understand customer preferences, improve operational processes, predict equipment maintenance needs, and respond to changing market conditions (Chui et al., 2017). AI-enabled systems and robots can operate continuously and perform repetitive tasks with consistent performance, allowing businesses to adjust production according to demand and reduce certain operational costs (Ford, 2015). However, effective implementation requires businesses to redesign complete processes rather than automate individual tasks in isolation. AI is also changing the nature of employment, as some routine activities become automated while new roles require employees to operate, maintain, and manage intelligent technologies. Robots are increasingly used in manufacturing, logistics, healthcare, restaurants, banking, and other service industries, demonstrating the expanding role of automation in business. Therefore, organizations need to analyze their processes, identify suitable applications of AI, monitor customer demand, and provide appropriate training and retraining for employees. Successful adoption of AI ultimately depends not only on the technology itself but also on how effectively businesses integrate it into their operations and workforce.

4. Artificial Intelligence and Employment

The increasing use of AI and automation is changing the nature of employment and creating uncertainty about the future of work. Some researchers argue that automation could eliminate large numbers of jobs if new employment opportunities do not develop quickly enough, while others suggest that technological change will create new occupations as older jobs decline (Clifton, 2011; Ford, 2015; Kaplan, 2017). Earlier evidence also indicates that technological development has already changed the structure of employment, with many occupations that existed decades ago no longer being available (Kaplan, 2017). At the same time, labor shortages and increasing demand for efficiency are encouraging businesses to adopt robots and other automated systems. The World Economic Forum identified advances in computing, big data, IoT, advanced manufacturing, 3D printing, AI, machine learning, and robotics as important drivers of future employment changes (World Economic Forum, 2016). Its projected compound growth rates also showed differences across job families, with Computer and Mathematical (3.21%) and Architecture and Engineering (2.71%) showing positive growth, while Office and Administrative occupations showed the largest projected decline (-4.91%). Frey and Osborne (2016) further estimated that a substantial share of U.S. employment was exposed to automation, although occupations involving creative, social, and certain physical skills were initially considered less susceptible. However, advances in robotics and machine perception continue to expand the range of tasks that machines can perform. Therefore, the impact of AI is likely to involve not only job displacement but also changes in job responsibilities, skill requirements, and human-machine collaboration. Businesses and workers will consequently need to emphasize retraining and skill development to adapt to changing workplace requirements.

Table 1. Projected compound growth rate of selected job families, 2015–2020

Job family	Growth rate
Computer and Mathematical	3.21%
Architecture and Engineering	2.71%
Management	0.97%
Business and Financial Operations	0.70%
Sales and Related	0.46%
Installation and Maintenance	-0.15%
Construction and Extraction	-0.93%
Arts, Design, Entertainment, Sports and Media	-1.03%
Manufacturing and Production	-1.63%
Office and Administrative	-4.91%

***Source**: World Economic Forum (2016, p. 16).*

5. AI Startups and Entrepreneurial Development

The growth of AI and other digital technologies is creating new opportunities for entrepreneurship and changing how economic value is generated and measured. Digital products and services can provide significant benefits through greater convenience, faster services, improved customer experiences, and better matching between users and providers, although many of these benefits are not fully reflected in conventional economic indicators such as GDP (Brynjolfsson & McAfee, 2014). The increasing availability of digital goods and services with little or no direct monetary price also creates challenges for traditional methods of measuring economic output. Although information-related industries represent a relatively small share of officially measured GDP, their actual contribution to economic and social value may be considerably broader (Brynjolfsson & McAfee, 2014). AI-driven entrepreneurship is part of this wider transformation, as startups can develop digital products and services that generate value through data, automation, and intelligent systems. At the same time, technological transformation can affect the distribution of income between labor and capital, particularly when machines and software perform an increasing number of productive activities. Brynjolfsson and McAfee (2014) therefore emphasize the importance of complementary indicators, including measures of human development, multidimensional poverty, and well-being, to better capture the broader effects of technological progress. These developments suggest that the contribution of AI startups should be considered not only in terms of revenue and employment but also in relation to innovation, consumer benefits, productivity, and wider social and economic value.

8. Conclusion

Artificial intelligence has developed from an emerging area of computer science into a major technological force affecting businesses, employment, entrepreneurship, and society. Its evolution has been supported by advances in machine learning, deep learning, computing power, cloud technologies, and the increasing availability of digital data. The integration of AI into business operations can improve efficiency, reduce operational costs, support decision-making, enhance customer services, and automate repetitive activities. However, these benefits also require organizations to redesign processes, develop appropriate implementation strategies, and prepare employees for changing job responsibilities. The analysis of employment trends indicates that AI and automation may reduce demand for some routine occupations while increasing the need for technical, analytical, creative, and other complementary skills. At the same time, AI is contributing to new entrepreneurial opportunities through digital products, services, and data-driven business models. The growth of AI startups further demonstrates the expanding commercial role of intelligent technologies, although conventional economic indicators may not fully capture their broader social and consumer benefits. Overall, the impact of AI extends beyond technological innovation and business productivity to include changes in employment, economic value creation, and social well-being. Therefore, realizing the potential benefits of AI requires continued technological development alongside workforce training, organizational adaptation, and broader consideration of its economic and societal consequences.

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KNOWLEDGE, ATTITUDES, AND PRACTICES REGARDING CARDIOPULMONARY RESUSCITATION AMONG HEALTHCARE PROFESSIONALS IN MARRAKECH, MOROCCO: A CROSS-SECTIONAL STUDY OF ASSOCIATED FACTORS

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ABSTRACT

Background: Cardiovascular disease and cardiac arrest are major causes of death worldwide. Early cardiopulmonary resuscitation performed by competent healthcare professionals is essential for survival. However, data on their knowledge, attitudes, and practices regarding cardiopulmonary resuscitation remain limited in the Marrakech prefecture.

Objective: Assess the knowledge, attitudes, and self-reported CPR practices of healthcare professionals in four types of healthcare facilities in the Marrakech prefecture and identify the factors associated with adequate and inadequate self-reported CPR practices.

Methods: A quantitative cross-sectional study was conducted among 331 physicians and nurses. Data were collected using a questionnaire comprising four sections (sociodemographic, knowledge, attitudes, and self-reported CPR practices), administered in both paper and online formats, and analysed using a descriptive and analytical approach.

Results: Negative perceptions of cardiopulmonary resuscitation were significantly associated with insufficient knowledge (Odds Ratio = 3.46, 95% Confidence Interval: 1.46–8.21), while adequate knowledge was linked to better self-reported CPR practices (Odds Ratio = 2.78, 95% Confidence Interval: 1.62–4.79). Healthcare professionals trained in CPR within the last two years were four times more likely to have adequate self-reported CPR practices (Odds Ratio = 4.08, 95% Confidence Interval: 1.24–13.36). In addition, nurse anaesthetists had significantly better self-reported CPR practices than other participants (Odds Ratio = 6.10, 95% Confidence Interval: 1.65–22.56).

***Conclusion*:** Recent training was significantly associated with better self-reported CPR practices, along with professional profile and clinical setting, while suboptimal results were observed in certain departments. These results underscore the importance of regularly updating healthcare professionals' knowledge and skills to optimize the management of cardiac arrests.
Keywords: Cardiopulmonary resuscitation (CPR), knowledge, attitudes, self-reported CPR practices, healthcare professionals, Associated factors

VITAMIN B12 DEFICIENCY–ASSOCIATED COGNITIVE DYSFUNCTION: PATHOPHYSIOLOGICAL MECHANISMS, CLINICAL EVIDENCE, AND THERAPEUTIC APPROACHES

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Abstract
Cognitive impairment is a major public health concern associated with aging and can substantially compromise quality of life and functional independence. Among the potentially modifiable risk factors, vitamin B12 deficiency has gained increasing attention because of its important role in maintaining neurological and cognitive function. Vitamin B12 is essential for myelin synthesis and maintenance, neurotransmitter metabolism, DNA synthesis, and homocysteine regulation. Its deficiency can disrupt these physiological processes and contribute to oxidative stress, neuroinflammation, vascular dysfunction, impaired neuronal integrity, and neurodegeneration, thereby potentially accelerating cognitive decline. This review critically examines evidence from human and animal studies concerning the association between vitamin B12 deficiency and cognitive dysfunction, while also evaluating the potential benefits and limitations of vitamin B12 supplementation. The review highlights the multifactorial etiology of vitamin B12 deficiency, including inadequate dietary intake, malabsorption, age-related physiological changes, and certain medical conditions, with older adults and individuals following vegetarian or vegan diets representing important at-risk populations. Emerging evidence on biochemical biomarkers, neuroimaging, and early diagnostic approaches may facilitate the identification of individuals at increased risk of deficiency-associated neurological impairment. Overall, timely screening, appropriate dietary strategies, and targeted vitamin B12 supplementation may help prevent or mitigate neurological and cognitive consequences associated with deficiency. Further well-designed longitudinal and interventional studies are required to establish causality and determine whether correcting vitamin B12 deficiency can meaningfully improve or prevent cognitive decline.

REAL ESTATE MANAGEMENT AND ENVIRONMENTAL SUSTAINABILITY

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ABSTRACT
The global real estate sector increasingly leverages Information and Communication Technology (ICT) to enhance efficiency, transparency, and service delivery. However, the level of adoption varies across regions, particularly in semi-urban contexts such as Jos. Unlike prior studies that focused on major metropolitan cities such as Lagos, Abuja, and Enugu, this study examines ICT adoption in Jos as an emerging urban center where limited empirical evidence exists in semi-urban Nigerian contexts. This study therefore extends ICT adoption literature by providing empirical evidence from a semi-urban real estate market and establishing baseline insights into the uneven adoption of basic and advanced ICT tools. This study examined Information and Communication Technology (ICT) adoption in real estate practice in Jos Metropolis, Nigeria, with particular emphasis on technological, organizational, and environmental factors associated with adoption and their implications for sustainable real estate practice. A quantitative survey design was employed using a census approach of all registered estate surveying firms in Jos (N = 80), yielding 67 valid responses (83.75% response rate). Data were analyzed using descriptive statistics, Relative Importance Index (RII), exploratory factor analysis, and multiple regression in SPSS version 26. Reliability of the constructs was confirmed using Cronbach's Alpha values ranging from 0.662 to 0.827, indicating moderate to good internal consistency. The suitability of the data for factor analysis was established with a Kaiser–Meyer–Olkin (KMO) value of 0.504 and a significant Bartlett's Test of Sphericity ($\chi^2 = 10.032$, $p = 0.018$). Results revealed a moderate overall level of ICT adoption (Mean = 2.83/5), with variations across indicators, as some practices such as ICT-based marketing and digital communication tools showed relatively higher adoption, while others remained low. Regression analysis showed that technological ($\beta = 0.328$; $t = 2.374$; $p = 0.021$), organizational ($\beta = 0.713$; $t = 10.354$; $p < 0.001$), and environmental ($\beta = 0.247$; $t = 3.456$; $p = 0.001$) factors significantly influenced ICT adoption, with organizational factors being the strongest predictor. The regression model exhibited a strong fit ($R^2 = 0.725$), explaining 72.5% of the variation in ICT adoption. The findings also indicate that increased ICT adoption has potential to support sustainable real estate practice through reduced paper-based operations, digital information management, remote communication, and more efficient property management. The study concludes that improving ICT integration in real estate practice requires continuous professional training, investment in digital infrastructure, and supportive government policies to enhance innovation and competitiveness.
Keywords: information and communication technology, real estate practice, technology adoption, environmental sustainability, sustainable development.

EXPLORING THE INNOVATIVE HOUSING FINANCE STRATEGIES IN ECO FRIENDLY REAL ESTATE DEVELOPMENT IN ABUJA ,NIGERIA

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ABSTRACT
Eco-friendly building and green Infrastructure are gaining more recognition in building industry especially due to their available material and cost efficiency. Sustainable building help in reducing, minimizing energy and conserving the environment. The study is to explore innovative housing finance strategies and their role in promoting eco-friendly real estate development in Abuja, focusing on innovative financing strategy available, level of success associated with the innovative housing finance strategies, challenges associated with accessing innovative housing finance strategies and effect of innovative housing finance strategies on the eco- friendly real estate development. A quantitative survey design was employed, and data were collected through structured questionnaires administered to 350 real estate developers, property professionals and other stakeholders involved in housing development within Abuja out of which, 302 were returned, representing 86.3% response rate. The sample was selected using proportional sampling technique to ensure fairness and representativeness. The study applied both descriptive and inferential statistical, including mean scores, standard deviation, and regression analysis using Statistical Package for Social Science (SPSS). Findings indicate that Public-Private Partnerships (PPP), government incentives, and tax incentives are most available and frequently utilized, while microfinance faces challenges. High interest rates and collateral requirements hinder access to finance, impacting project success. Regression analysis shows a significant positive relationship between financing innovation and housing availability, emphasizing the critical role of financial mechanisms in sustainable urban development. Policies promoting innovative financing can enhance eco-friendly housing delivery, address urban housing shortages and foster environmental sustainability. There is a need to adopt eco-friendly building strategies model which will assist in reducing energy consumption and also provide a suitable shelter, environment for development of real estate and other infrastructure in the metropolitan cities.
Keywords: Eco-friendly real estate development, green infrastructure, innovative housing finance, Real estate development, residential property

MATERNAL ZINC STATUS DURING PREGNANCY: IMPLICATIONS FOR ANEMIA AND GESTATIONAL HEALTH

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ABSTRACT

Background: Zinc is an essential micronutrient involved in cellular growth, immune regulation, protein synthesis, and fetal development. Pregnancy is associated with increased micronutrient requirements, making maternal zinc status particularly important during periods of rapid fetal growth. Inadequate zinc availability may coexist with other nutritional deficiencies and could contribute to impaired maternal hematological status and unfavorable pregnancy outcomes.

Aim:To evaluate maternal zinc status during pregnancy and investigate its potential relationship with hemoglobin levels, anemia, and gestational characteristics in a cohort of pregnant women.

Materials and Methods: This observational study was designed to include 100 pregnant women, with maternal zinc concentrations assessed primarily during the second trimester. Participants were classified according to zinc status into women with decreased and adequate serum zinc concentrations. Maternal age, gestational age, hemoglobin concentration, anemia status, and available micronutrient parameters, including vitamin D, were considered for analysis. Correlation and comparative analyses were planned to investigate potential relationships between zinc status and maternal hematological and gestational parameters.

Results: Preliminary evaluation indicated considerable variability in maternal zinc concentrations, suggesting heterogeneous micronutrient status during pregnancy. Reduced zinc levels were observed in a proportion of the evaluated women and appeared to coexist with lower hemoglobin concentrations in some cases. The planned analysis of the complete 100-patient cohort will determine the prevalence of zinc deficiency and quantify its relationship with maternal hemoglobin, anemia, gestational age, and other micronutrient parameters. Particular attention will be given to the potential coexistence of zinc deficiency and anemia as indicators of maternal nutritional vulnerability. **Conclusions:** Assessment of zinc status may represent an important component of nutritional evaluation during pregnancy. The potential coexistence of reduced zinc concentrations and anemia highlights the need for a broader approach to maternal micronutrient assessment rather than focusing exclusively on iron status. Identification of women with inadequate zinc status could support more individualized nutritional counseling and supplementation strategies during pregnancy. Larger prospective studies are required to determine whether maternal zinc concentrations can predict clinically relevant maternal or fetal outcomes.

Keywords: zinc; pregnancy; micronutrients; anemia; hemoglobin; maternal nutrition; gestational health.

ENVIRONMENTAL ARCHAEOLOGY IN JORDAN: HOW THE ENVIRONMENT SHAPED ANCIENT CIVILIZATIONS

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Abstract
Archaeology is the branch of archaeology that studies the reciprocal relationship between ancient humans and their environment over time. It does not merely answer the question of what humans built, but rather addresses how they lived, what they ate, and how climatic shifts impacted the collapse or prosperity of their societies. In Jordan, this discipline relies on several specialized sub-fields, including but not limited to the following: Zoo archaeology: The study of animal bones and teeth to understand the processes of animal domestication, such as goats, sheep, and camels, as well as ancient dietary patterns. Archaeobotany or Palaeobotany: The analysis of charcoal, seeds, charred grains, and plant impressions to trace the origins of agriculture, including wheat, barley, and olive cultivation. Geoarchaeology: The study of soils, sediments, and hydrological changes to determine how wadi courses and ancient lake levels altered over time, such as the ancient Azraq Lake. Case Studies and Applications from Jordanian Sites Field surveys and archaeological excavations have revealed numerous sites where the environment played a pivotal role in shaping early human communities, serving as a Launchpad for their historical achievements. Among the most prominent of these sites are the following: Ain Ghazal (Amman - Neolithic Period): Environmental studies revealed early evidence of animal domestication and the inception of the first agricultural crop mix. Analyses demonstrated that overgrazing and deforestation, driven by building construction and lime-plaster production, led to local environmental degradation, which ultimately forced residents to adapt their lifestyle. Azraq and Zarqa Sites (Paleolithic Period and Prehistory): Geoarchaeological and zoo archaeological studies proved that the Zarqa and Azraq regions were once lush green oases abundant with water and megafauna, such as ancient elephants and mammoths, particularly Elephas antiquus. The region has yielded significant fossil discoveries, including dinosaur teeth and the giant pterosaur named Arambourgiania philadelphiae, dated to approximately seventy million years ago, alongside other fossil remains in the Zarqa Valley. Furthermore, laboratory tests conducted on flint tools recovered from the Zarqa Valley confirmed that they date back two and a half million years to the early humans who inhabited the area. This discovery challenges the theory that human origins were exclusively confined to Africa. Wadi Faynan (Tafileh - Chalcolithic and Bronze Ages): This site represents an industrial environment centered on copper smelting and alloying with tin. It provides evidence of some of the earliest human-induced environmental pollution in history, highlighting the ecological impact of ancient mining activities. The Nabataeans and Desert Agriculture (Petra and the South): The Nabataeans thoroughly understood their semi-arid environment and invented ingenious rainwater harvesting techniques to manage flash floods and utilize every drop of rain. Significance of Environmental Archaeology for Modern Jordan Understanding Climate Change: This discipline helps us comprehend how ancient civilizations adapted to recurring dry climatic cycles, offering valuable insights for managing present-day water scarcity. Resource Management: It inspires sustainable ancient solutions, such as the Nabatean water harvesting system, to address modern environmental challenges.
Keywords: Environment, Old Civilization, Heritage, Pollution, South Levant.

MENOPAUSAL SYMPTOM BURDEN AS A HEALTHCARE PRIORITY: A QUESTIONNAIRE-BASED ASSESSMENT OF WOMEN'S CARE NEEDS

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ABSTRACT

Background: Menopause is a multidimensional transition associated with vasomotor, psychological, somatic, and urogenital manifestations that may substantially affect quality of life and healthcare needs. Despite their frequency, menopausal symptoms are not always systematically assessed during routine medical visits. Patient-reported questionnaires may facilitate the identification of unmet needs and support more personalized healthcare strategies. **Aim:** To assess menopausal symptom burden among women attending gynecological care and to identify the principal symptom domains that should be prioritized in comprehensive menopause healthcare.

Materials and Methods: This cross-sectional analysis included a randomly selected sample of 120 menopausal women with complete questionnaire data. Eleven menopausal symptoms were evaluated, covering somatic, psychological, and urogenital domains. Symptoms included hot flushes and sweating, cardiac complaints, sleep disturbances, depressive mood, irritability, anxiety, physical and mental exhaustion, sexual problems, bladder symptoms, vaginal dryness, and musculoskeletal complaints. Symptom intensity was graded according to severity, and an overall symptom score was calculated.

Results: The mean age of participants was 49.82 ± 7.78 years, and 75.0% lived in urban areas. Vasomotor symptoms represented the most prevalent complaint, with 89.2% of women reporting hot flushes or sweating and 59.2% experiencing moderate-to-severe symptoms. Sleep disturbances affected 81.7% of participants, followed by physical and mental exhaustion (71.7%) and musculoskeletal complaints (70.0%). Urogenital manifestations were also frequent: vaginal dryness was reported by 65.8%, sexual problems by 62.5%, and bladder symptoms by 60.0% of women. Psychological manifestations included irritability (50.8%), depressive mood (44.2%), and anxiety (42.5%). The mean overall symptom score was 11.17 ± 6.00, demonstrating a substantial and multidimensional menopausal symptom burden.

Conclusions: Menopausal symptom burden represents an important women's healthcare issue extending considerably beyond vasomotor complaints. Sleep disturbances, fatigue, musculoskeletal symptoms, and urogenital manifestations were highly prevalent and should be actively evaluated during routine healthcare encounters. Integrating standardized patient-reported symptom assessment into menopause care could facilitate earlier identification of unmet needs, improve patient–clinician communication, and support more personalized and multidisciplinary healthcare interventions.
Keywords: menopause; healthcare; women's health; symptom burden; patient-reported outcomes; quality of life; personalized care.

EVALUATION OF THE BIOCHEMICAL AND ANTIOXIDANT PROPERTIES OF CULTIVATED AND WILD JUJUBE (ZIZIPHUS JUJUBA MILL.) GENOTYPES

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ABSTRACT
Jujube (*Ziziphus jujuba* Mill.) is a fruit species that has attracted increasing attention in recent years due to its high nutritional value and content of biologically active compounds. This study aimed to compare the biochemical properties and antioxidant potential of cultivated and wild jujube materials. In this context, total phenolic content, DPPH radical-scavenging activity, soluble solids content (SSC), sugars, and organic acids were analyzed in the fruits. The results revealed marked biochemical differences between the two materials. Wild jujube fruits exhibited higher total phenolic content (198.86 mg GAE/100 g) and DPPH activity (91.72%) than cultivated jujube, indicating a stronger antioxidant capacity. In contrast, SSC was higher in cultivated jujube (22.70%) than in wild jujube (16.97%), indicating a greater soluble solids content in the cultivated material. Regarding the sugar profile, sucrose (11.35%), glucose (5.25%), fructose (5.07%), and total sugar (21.68%) contents were higher in cultivated jujube than in wild jujube (7.85%, 3.84%, 4.60%, and 16.30%, respectively). In terms of organic acids, wild jujube had higher citric acid (1.43%), malic acid (1.46%), and ascorbic acid (1.32%) contents than the cultivated material, whereas succinic acid contents were relatively similar between the two materials. These findings demonstrated that cultivated and wild jujube materials differ considerably in terms of their quality components, with wild jujube showing particular potential due to its higher phenolic content, antioxidant capacity, and organic acid levels. In contrast, the higher SSC and sugar contents of cultivated jujube indicate a sweeter and potentially more palatable fruit profile for consumers. Therefore, wild jujube can be considered a valuable genetic resource in terms of bioactive compounds with high biological activity, while cultivated forms stand out for their taste and consumer-oriented quality attributes. Both materials have considerable potential for use in breeding programs and functional food research.
Keywords: Antioxidant activity, genotype, jujube, organic acids, sugars, *Ziziphus jujuba* Mill.

INTRODUCTİON
Jujube (*Ziziphus jujuba* Mill.) is an important fruit species belonging to the Rhamnaceae family that is well adapted to warm and subtropical climatic conditions and can be consumed both fresh and dried. The genus Ziziphus comprises approximately 40 species and is widely distributed, particularly in Southeast Asia, China, and the warm regions of the Mediterranean (Singh and Arya, 2011). The center of origin of jujube is reported to be Yunnan Province of China, where it has been cultivated for food and medicinal purposes for approximately 7,000 years (Mengjun, 2003). With a natural distribution extending from Russia, the Middle East, India, and Southern Europe to Anatolia and North Africa, the species has become an important fruit crop, particularly in Asian countries, owing to its wide adaptability, early maturation, long lifespan, high nutritional value, versatile uses, and ease of cultivation (Mengjun, 2003; Liu, 2003). Today, *Ziziphus jujuba* Mill. is one of the economically and culturally most important species within the genus Ziziphus, with approximately 1.5 million ha under cultivation worldwide, an annual production exceeding 8 million tons, and a total annual production value exceeding 15 billion US dollars (Liu et al., 2014).

In Türkiye, jujube is mainly cultivated in the Marmara, Western, and Southern Anatolia regions, where both cultivated and naturally occurring materials can be found (Singh and Arya, 2011). It is cultivated in provinces such as Isparta, Hatay, İskenderun, Antalya, Kayseri, Bursa, Çanakkale, İstanbul, Tekirdağ, Sinop, and Aydın, while natural populations are particularly common in Denizli (Davis, 1967; Karıncalı, 2003; Kavas and Dalkılıç, 2015). This wide distribution enables the occurrence of jujube genotypes adapted to different ecological conditions and consequently contributes to considerable variation in the morphological and biochemical characteristics of the fruits.

The high nutritional value and biologically active compounds of jujube fruit have increased its importance as a functional fruit. The fruits are rich in carbohydrates, vitamins, phenolic compounds, flavonoids, saponins, and polysaccharides, which contribute significantly to their nutritional and functional value (Li et al., 2005; Li et al., 2007). In particular, vitamin C, phenolic compounds, and flavonoids are among the major constituents associated with the biological activity and antioxidant potential of jujube fruit (Gao et al., 2013). In addition to these constituents, the long-standing traditional medicinal use of jujube has increased interest in its potential as a nutraceutical and functional food source. Indeed, Ziziphus species have traditionally been used in various therapeutic applications in Asian countries, and jujube fruit is reported to be rich in compounds exhibiting diverse biological activities (Li et al., 2005). Soluble solids content (SSC), sugars, and organic acids are important indicators in the assessment of fruit quality. Sucrose, glucose, and fructose are the major sugar components of jujube fruits, whereas citric, malic, and succinic acids are among the major organic acids detected in the fruit. Gao et al. (2012) reported significant differences in sugar and organic acid profiles among different jujube selections according to genotype and emphasized that SSC and total sugar content are important criteria for fruit consumption quality. Similarly, a study examining 15 jujube cultivars demonstrated considerable differences in sugar and organic acid composition among cultivars (Wang et al., 2018). These variations indicate that the taste, flavor, and consumer quality of jujube fruit may vary depending on genotype and growing conditions.

Phenolic compounds and antioxidant capacity are also important parameters for evaluating the functional properties of jujube fruit. Various phenolic compounds, including gallic acid, chlorogenic acid, caffeic acid, ferulic acid, p-hydroxybenzoic acid, and p-coumaric acid, have been identified in jujube fruit, and these compounds have been reported to contribute to the reduction of free radical activity (Muchuweti et al., 2005; Zhang et al., 2010). In addition, caffeic acid, ferulic acid, and other phenolic compounds contribute substantially to the antioxidant capacity of jujube (Kamiloğlu et al., 2009; Zhang et al., 2010). The ability of phenolic compounds to act as hydrogen or electron donors through their hydroxyl groups enables them to play an important role in limiting free-radical chain reactions associated with oxidative stress (John and Shahidi, 2010). Fruits and vegetables are important sources of natural antioxidants such as vitamin C, tocopherols, phenolic compounds, and β-carotene, which contribute to limiting oxidative damage caused by free radicals. Reactive oxygen species can interact with biological molecules such as proteins, carbohydrates, DNA, and RNA, resulting in cellular damage, whereas naturally derived antioxidants play a protective role against these processes. Therefore, increasing attention has been directed toward the identification and evaluation of plant-based sources with high antioxidant capacity. In particular, phenolic-rich foods have been extensively investigated because of their potential role in preventing or reducing the risk of chronic diseases such as cardiovascular diseases, cancer, Alzheimer's disease, and diabetes (John and Shahidi, 2010). The antioxidant activity of jujube is also considered to be associated with its high levels of phenolic compounds, particularly chlorogenic, gallic, protocatechuic, and caffeic acids (Zhang et al., 2010). San and Yıldırım (2010) likewise reported jujube as an important source of phenolic compounds.

The potential health benefits of biologically active compounds present in jujube fruit have also been demonstrated by several researchers. Previous studies have reported health-promoting compounds in different jujube genotypes (Akbolat et al., 2008; Li et al., 2005; Li et al., 2007), while jujube fruits and their products have been suggested to possess protective potential against various chronic diseases (Kalt et al., 1999). Therefore, it is important to characterize fruits not only in terms of their basic nutritional value but also according to their specific antioxidant compounds and total antioxidant capacity (Ercisli and Orhan, 2007). More detailed information on health-promoting compounds in jujube genotypes may contribute to a better understanding of the pharmaceutical, nutraceutical, and functional food potential of this fruit.

The chemical composition of jujube fruit is influenced not only by genotype but also by the developmental and maturation stage of the fruit. Gündüz and Saraçoğlu (2014) reported significant changes in SSC, total phenolic content, antioxidant capacity, sugars, and organic acids in jujube fruits harvested at different maturity stages, with SSC particularly increasing during maturation. Wojdyło et al. (2016) also demonstrated significant differences in total polyphenol content, ascorbic acid content, and antioxidant capacity among different jujube cultivars grown in Spain. These findings indicate that genotype and maturity stage are important factors determining the biochemical composition of jujube fruit.

Cultivated and naturally occurring wild jujube materials may exhibit different fruit quality and biological activity profiles due to their distinct genetic characteristics and adaptation to environmental conditions. While traits such as high fruit size, SSC, sugar content, and consumer quality may have been favored through selection in cultivated materials, wild materials may possess distinctive and valuable characteristics in terms of biologically active compounds as a result of natural selection and adaptation to environmental stresses. Studies comparing different jujube genotypes have also demonstrated that genotype has a significant effect on fruit quality characteristics, including sugars, organic acids, phenolic compounds, and antioxidant capacity (Gao et al., 2012; Wojdyło et al., 2016). Therefore, comparing wild and cultivated jujube materials in terms of their biochemical characteristics is important for evaluating existing genetic resources and identifying materials with superior characteristics. The present study aimed to compare cultivated and wild jujube (*Ziziphus jujuba* Mill.) fruits in terms of total phenolic content, DPPH radical-scavenging activity, soluble solids content, sucrose, glucose, fructose and total sugar contents, as well as citric, malic, ascorbic, and succinic acid contents. Thus, the study sought to evaluate both the basic chemical characteristics determining consumer quality and the phenolic content and antioxidant capacity reflecting the functional properties of the two materials. The results are expected to contribute to revealing the valuable biochemical characteristics of wild jujube and to the future utilization of cultivated and wild materials in selection, breeding, and functional food research.

MATERIALS and METHODS

Materials

The study was conducted at the research area of the Department of Horticulture, Faculty of Agriculture, Çukurova University (37°01'42"N, 35°22'00"E). Three-year-old, single-trunk *Ziziphus jujuba* Mill. trees grown as cultivated jujube and trained using a central leader system, with a planting distance of 4 × 2 m, were used as the cultivated plant material. Naturally occurring wild jujube plants located in the same area were used as the wild plant material. Standard fertilization, irrigation, and disease control practices were applied to the cultivated plants. Fruits from both cultivated and wild jujube materials were harvested at the appropriate harvest stage and used for biochemical analyses.

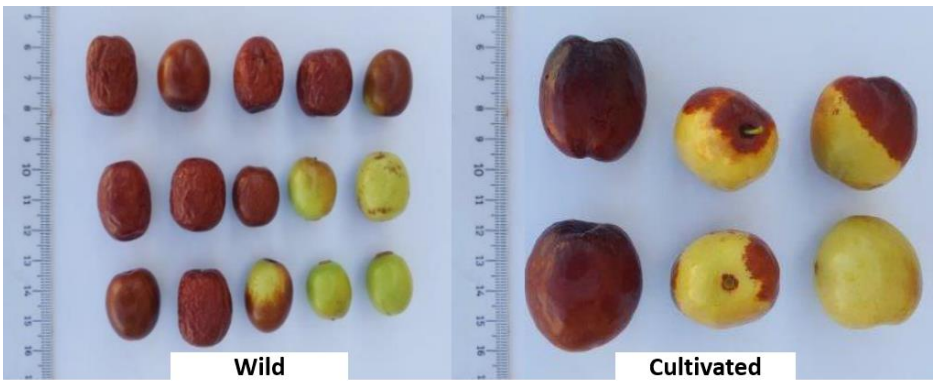


Figure 1. Materials used in the study.

Method

Determination of Total soluble solid

After harvesting, the fruits were washed with water and dried at room temperature. The jujube was halved, and the juice was extracted using a standard laboratory juice extractor.

The extracted juice was filtered through cheesecloth to remove seeds and coarse pulp particles and then thoroughly homogenized. The juice samples were centrifuged at 5.000 rpm for 10 min at 4 °C, and the resulting supernatant was used for subsequent physicochemical and biochemical analyses. Total soluble solids in jujube juice (TSS, %) were determined using a hand refractometer (Atago, Japan).

Determination of Total Phenolic Content

Total phenolic content of jujube juice was determined colorimetrically using the Folin–Ciocalteu reagent according to Urun et al. (2021) and Spanos and Wrolstad (1990). Briefly, 1 mL of fruit juice was mixed with 9 mL of 80% methanol and centrifuged. Then, 50 µL of the supernatant was mixed with 250 µL of Folin–Ciocalteu reagent and 750 µL of 20% sodium carbonate solution. The reaction mixture was thoroughly mixed and incubated for 30 min at room temperature before absorbance was measured at 760 nm using a UV–Vis spectrophotometer (Thermo Scientific Multiskan GO, Waltham, MA, USA). Gallic acid (Sigma-Aldrich, St. Louis, MO, USA) was used as the standard, and the results were expressed as mg gallic acid equivalents per 100 g fresh weight (mg GAE 100 g^{-1} FW).

Determination of Total Antioxidant Capacity

Antioxidant capacity was assessed using the DPPH radical scavenging assay with slight modifications of the method described by Brand-Williams et al. (1995). Fresh jujube juice was obtained by manually squeezing the fruits and filtering through cheesecloth to remove seeds and coarse pulp. The juice samples were centrifuged at 5,000 rpm for 10 min at 4 °C, and the resulting supernatant was used for antioxidant analyses. A freshly prepared ethanolic DPPH solution (0.06 mM) was used for antioxidant activity determination. In the assay, 50 µL of jujube juice extract was mixed with 1.95 mL of DPPH solution, resulting in a total reaction volume of 2.0 mL and incubated for 30 min. Absorbance was then measured at 515 nm using a spectrophotometer. There, Abs blank is the absorbance of the control solution containing DPPH without sample, Abs sample is the absorbance of the reaction mixture containing the sample extract, and t is the incubation time prior to absorbance measurement. (Thermo Scientific Multiskan GO Waltham MA USA) DPPH inhibition (%) was calculated as:

$$Inhibition\ \% = \frac{\text{Absorbance blank (t } = \text{ 30)} - \text{(Absorbance sample)}}{\text{Absorbance blank (t} = \text{ 30)}}\ x\ 100$$

High-Performance Liquid Chromatography (HPLC) Analysis of Sugars

Glucose, fructose, sucrose, and xylose contents were determined by high-performance liquid chromatography (HPLC) according to Crisosto (1997). Frozen fruit samples were thawed at 25 °C, and 1 g of homogenized pulp was mixed with 4 mL of ultrapure water (Millipore Corp., Bedford, MA, USA). The mixture was sonicated for 15 min and centrifuged (Elektro-Mag, EMX-125-Türkiye) at 5500 rpm for 15 min. The supernatant was filtered through 0.45 µm nylon syringe filters (Whatman, 13 mm) prior to analysis. HPLC analysis was performed using a Shimadzu system (Kyoto, Japan) equipped with a refractive index detector (RID) and a CARBOSep COREGEL 87C column (7.8 × 100 mm). Separations were conducted at 75 °C with a flow rate of 0.6 mL min^{-1} using ultrapure water as the isocratic mobile phase. Sugar contents were expressed as percentage fresh weight (FW) (Urun et al. 2021).

Determination of Organic Acids

Organic acids (malic, citric, succinic, and L-ascorbic acids) were analyzed by HPLC according to Bozan et al. (1997) with minor modifications. Fresh jujube juice was obtained as described above and centrifuged at 5,000 rpm for 10 min at 4 °C. Subsequently, 1 mL of the clear supernatant was mixed with 4 mL of 3% metaphosphoric acid (Sigma-Aldrich, St. Louis, MO, USA), sonicated at 80 °C for 15 min, and centrifuged at 5.500 rpm for 15 min. The extract was filtered through 0.45 µm nylon syringe filters prior to analysis. HPLC analysis was carried out using a Shimadzu LC-20A VP system equipped with a UV detector (SPD-20A VP) and a COREGEL 87H column (5 µm, 300 × 7.8 mm; Transgenomic, USA). The column temperature was set to 40 °C, the injection volume was 20 µL, the detection wavelength was 210 nm, and the flow rate was 0.8 mL min^{-1}. A 0.05 mM sulfuric acid solution (Merck KGaA, Darmstadt, Germany) was used as the mobile phase.

Statistical Analysis

The data obtained from the study were analyzed using IBM SPSS Statistics 22 software. An independent-samples t-test was performed to determine the statistical significance of the differences between the cultivated and wild jujube fruits.

RESULTS and DİSCUSSİON

When the biochemical properties of cultivated and wild jujube fruits were evaluated, marked differences were observed between the two materials, particularly in terms of antioxidant capacity, sugar profile, and organic acid composition. Regarding antioxidant properties, the total phenolic content was 198.87 mg GAE/100 g in wild jujube, whereas it was 109.73 mg GAE/100 g in cultivated jujube. Similarly, DPPH radical-scavenging activity was 91.72% in wild jujube and 82.31% in cultivated jujube (Table 1). The differences between the two materials were statistically significant at the 1% level ($p<0.01$). The higher total phenolic content and DPPH activity observed in wild jujube indicate a stronger antioxidant potential. This finding is consistent with previous studies reporting that phenolic compounds make an important contribution to the antioxidant capacity of jujube fruits (Gao et al., 2012; Zhang et al., 2010). Gao et al. (2012) reported total phenolic contents ranging from 275.6 to 541.8 mg GAE/100 g fresh weight among 10 promising jujube selections and demonstrated a strong relationship between phenolic compounds and antioxidant activity. In the present study, the total phenolic contents of both cultivated and wild jujube were lower than the range reported by Gao et al. (2012). However, differences in genotype, growing conditions, maturity stage, extraction procedure, and analytical methods may substantially affect the measured phenolic content. Similarly, Wojdyło et al. (2016) reported considerable variation in total polyphenol content among Spanish jujube cultivars and emphasized the importance of genotype in determining the antioxidant potential of the fruit. Therefore, the higher phenolic content and DPPH activity observed in the wild material in the present study may be associated with genotypic differences and adaptation to environmental conditions.

The DPPH radical-scavenging activity was 91.72% in wild jujube and 82.31% in cultivated jujube, and the difference was significant at the 1% level ($p<0.01$) (Table 1). The higher antioxidant activity of wild jujube was consistent with its higher total phenolic content. Gao et al. (2012) reported a strong relationship between total phenolic content and antioxidant activity in different jujube selections. Similarly, Wojdyło et al. (2016) found significant differences in antioxidant capacity among different Spanish jujube cultivars. kmekçi (2024) reported total antioxidant activity values ranging from 1.58–6.69 mg CE/g DW, 1.58–3.24 mmol TE/g, and 0.17–1.27 mmol TE/g at the green-white, semi-reddish, and fully reddish maturity stages, respectively. The results obtained in the present study therefore support the view that genetic variation may contribute substantially to differences in the antioxidant potential of jujube fruits. The antioxidant activity observed in the present study was higher than that reported by

In terms of soluble solids content (SSC), cultivated jujube had a significantly higher value (22.70%) than wild jujube (16.97%) ($p<0.01$). Ekmekçi (2024) reported that soluble solids content (SSC) ranged from 7.35–17.37%, 14.90–22.80%, and 15.90–25.85%, while titratable acidity (TA) ranged from 0.071–0.241, 0.122–0.330, and 0.14–0.35 g/100 mL in the green-white, semi-reddish, and fully reddish maturity stages, respectively. Both SSC and TA increased with advancing maturity. Geçer and Yılmaz (2026) for jujube fruits subjected to postharvest putrescine treatments. They reported that the control treatment showed the highest soluble solids content (29.55%), pH (4.89), titratable acidity (0.28%), and total antioxidant activity (38.92%). Gündüz and Saraçoğlu (2014) reported SSC values ranging from 12.8 to 18.3% in jujube fruits harvested at different maturity stages and observed that SSC increased with fruit maturation. The SSC value of cultivated jujube in the present study was slightly higher than the upper limit reported by Gündüz and Saraçoğlu (2014), whereas the value recorded for wild jujube was within the reported range. Such differences may be related to genotype, environmental conditions, fruit maturity, and cultural practices.

The sugar profile further supported the differences observed in SSC. Sucrose (11.36%), glucose (5.25%), fructose (5.07%), and total sugar (21.68%) contents were higher in cultivated jujube than in wild jujube, which had values of 7.86%, 3.84%, 4.61%, and 16.31%, respectively. All differences were statistically significant at the 1% level ($p<0.01$) (Table 1).

Gao et al. (2012) reported that sucrose, glucose, and fructose are the major sugars in jujube fruits and that their concentrations vary considerably among genotypes. Similarly, Wang et al. (2018) demonstrated substantial differences in sugar composition among 15 jujube cultivars. These findings are consistent with the present results and indicate that genotype plays an important role in determining the sugar profile and consequently the sweetness and consumer quality of jujube fruits. The higher SSC and total sugar content observed in cultivated jujube may therefore contribute to a sweeter and more desirable fresh-fruit profile.Hernández et al. (2016) reported that the total sugar content of jujube cultivars ranged from 10.8% to 15.0%**,** with the highest value found in 'GAL' (15.0%) and the lowest in 'PSI' (10.8%). In their study, fructose, glucose, and sucrose contents ranged from 4.8% to 5.7%**,** 3.0% to 3.9%**,** and 1.6% to 9.4%, respectively. The 'MSI' cultivar was particularly distinguished by its high fructose (5.7%) and sucrose (9.4%) contents. High fructose levels in jujube fruits have been reported to contribute substantially to their characteristic sweetness and to play an important role in determining fruit flavor (Li et al., 2007; Gao et al., 2011; Gao et al., 2012; Hernández et al., 2016).

Regarding organic acid composition, wild jujube showed considerably higher values for several compounds. Citric acid, malic acid, and L-ascorbic acid contents were 1.47%, 1.46%, and 1.32%, respectively, in wild jujube, compared with 0.73%, 0.97%, and 0.60% in cultivated jujube. The differences were statistically significant at the 1% level ($p<0.01$) (Table 1). Previous research has demonstrated considerable variation in the organic acid composition of jujube fruits depending on genotype. Gao et al. (2012) reported that malic, citric, and succinic acids are among the major organic acids found in jujube fruits. Likewise, Wang et al. (2018) reported significant differences in organic acid composition among 15 jujube cultivars. Thus, the higher citric and malic acid contents observed in the wild material in the present study are consistent with the genotypic variation previously reported for jujube. Wojdyło et al. (2016) reported substantial differences in ascorbic acid content among Spanish jujube cultivars, further demonstrating the importance of genotype in determining the nutritional quality of jujube fruit. The higher ascorbic acid content observed in the wild material in the present study suggests that naturally occurring jujube genotypes may possess valuable nutritional characteristics. However, direct numerical comparisons should be made cautiously because differences in units, extraction procedures, analytical methods, and expression on a fresh- or dry-weight basis can influence the reported values. Gao et al. (2012) identified succinic acid as one of the organic acids present in jujube fruit, together with citric and malic acids. The relatively similar succinic acid levels observed between the two materials in the present study indicate that this component may be less affected by the differences between the cultivated and wild materials than the other organic acids investigated.Hernández et al. (2016) reported that the total organic acid content of jujube fruits ranged from 1.83% to 7.16%, with the highest value recorded in the 'PSI' cultivar (7.16%) and the lowest in the 'DAT' cultivar (1.83%). The 'PSI' cultivar, which had both a high total organic acid content and a high citric acid content, may therefore have a more pronounced acidic taste profile. Indeed, the researchers reported that differences in organic acid content were also reflected in titratable acidity (TA) values and that a strong relationship was observed between total organic acid content and TA (R^2 = 0.74). In the same study, the ascorbic acid content ranged from 0.41% to 0.64%, with the highest value recorded in the 'PSI' cultivar (0.64%) and the lowest in the 'DAT' cultivar (0.41%).

Overall, the results demonstrate clear biochemical differentiation between cultivated and wild jujube fruits. Cultivated jujube was characterized by higher SSC and sugar contents, indicating a potentially sweeter and more consumer-oriented fruit profile, whereas wild jujube exhibited higher total phenolic content, DPPH radical-scavenging activity, citric acid, malic acid, and L-ascorbic acid contents, indicating a stronger functional and nutritionally valuable profile. These findings are generally consistent with previous reports demonstrating substantial genotypic variation in the sugar, organic acid, phenolic, and antioxidant characteristics of jujube fruits (Gao et al., 2012; Gündüz and Saraçoğlu, 2014; Wang et al., 2018; Wojdyło et al., 2016). Consequently, the wild jujube material evaluated in this study may represent a valuable genetic resource for the identification and selection of genotypes with high antioxidant and bioactive compound contents, while cultivated jujube may be particularly valuable for fresh consumption due to its higher SSC and sugar contents. The complementary characteristics of these two materials highlight their potential importance for jujube breeding, genetic resource conservation, and functional food research.

Table 1. Phytochemical and Biochemical Characteristics of Wild and Cultivated Jujube Genotypes

Parameter	Cultivated jujube	Wild jujube	*t*-Student test (*p* value)
DPPH (%)	82.31 ± 3.46	91.72 ± 0.68	<0.01**
Total phenolic content (mg GAE/100 g)	109.73 ± 2.16	198.87 ± 31.63	<0.01**
Total soluble solids (TSS, %)	22.70 ± 0.50	16.97 ± 0.14	<0.01**
Sucrose (%)	11.36 ± 0.04	7.86 ± 0.05	<0.01**
Glucose (%)	5.25 ± 0.06	3.84 ± 0.07	<0.01**
Fructose (%)	5.07 ± 0.04	4.61 ± 0.03	<0.01**
Total sugar (%)	21.68 ± 0.04	16.31 ± 0.03	<0.01**
Citric acid (%)	0.73 ± 0.06	1.47 ± 0.17	<0.01**
Malic acid (%)	0.97 ± 0.09	1.46 ± 0.01	<0.01**
L-Ascorbic acid (%)	0.60 ± 0.06	1.32 ± 0.17	<0.01**
Succinic acid (%)	0.22 ± 0.01	0.24 ± 0.01	>0.05

Values are presented as mean ± standard deviation. Significant at the 1% probability level (***p***<0.01); ns: not significant (***p***>0.05).

CONCLUSIONS

In study, the biochemical properties of cultivated and wild jujube (Ziziphus jujuba Mill.) materials were compared, and significant differences were identified between the two materials. Cultivated jujube stood out due to its higher total soluble solids and total sugar contents. The higher sucrose, glucose, and fructose contents compared with wild jujube indicated that cultivated material has an important advantage in terms of sweetness and fresh fruit quality. In contrast, the higher total phenolic content and DPPH radical-scavenging activity observed in wild jujube demonstrated that the wild material possesses a stronger antioxidant potential. Furthermore, the higher contents of citric acid, malic acid, and L-ascorbic acid in wild jujube compared with the cultivated material indicated that wild jujube has considerable potential in terms of nutritional and functional properties. No statistically significant difference was observed between cultivated and wild materials regarding succinic acid content.

In conclusion, cultivated jujube appears to be superior in terms of fresh consumption quality due to its higher total soluble solids and sugar contents, whereas wild jujube represents an important genetic resource with respect to its higher phenolic content, antioxidant activity, and organic acid composition. Therefore, it is recommended that wild jujube populations containing genotypes with superior biochemical characteristics should be identified, conserved, and utilized in future selection and breeding programs. Furthermore, combining the superior consumer-quality characteristics of cultivated materials with the high biological activity and functional properties of wild materials may contribute to the development of new jujube cultivars with improved quality traits as well as functional food products and natural antioxidant sources. Future studies involving a larger number of cultivated and wild jujube genotypes evaluated across different regions and growing seasons would also provide a more comprehensive understanding of the biochemical diversity present in jujube genetic resources.

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MERSİN YÖRESİNDE YETİŞTİRİLEN BAZI PİTAYA (HYLOCEREUS SPP.) ÇEŞİTLERİNİN MEYVE KALİTE ÖZELLİKLERİNİN DEĞERLENDİRİLMESİ

EVALUATION OF FRUIT QUALITY CHARACTERISTICS OF SOME PITAYA (HYLOCEREUS SPP.) CULTIVARS GROWN IN THE MERSIN REGION

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ÖZET

Pitaya (*Hylocereus spp*.), sahip olduğu farklı meyve renkleri, kendine özgü morfolojik özellikleri ve tüketici açısından dikkat çekici kalite özellikleri nedeniyle son yıllarda alternatif meyve türleri arasında öne çıkmaktadır. Bununla birlikte, farklı genotiplerin meyve büyüklüğü, renk özellikleri ve kimyasal bileşimleri bakımından gösterdiği varyasyon, yetiştiricilik ve genotip seçimi açısından önemli bir değerlendirme kriteridir. Bu çalışmada, farklı pitaya genotiplerinin pomolojik ve bazı fizikokimyasal özelliklerinin ortaya konulması amaçlanmıştır. Bu kapsamda Conie Mayer, Pepino Dulce, Philippines Purple, Golden Yellow ve Natural Mystic genotiplerinde kabuk ve meyve eti renk özellikleri ile meyve ağırlığı, meyve boyu, meyve eni, titre edilebilir asitlik, pH ve suda çözünür kuru madde (SÇKM) içerikleri belirlenmiştir. İncelenen genotiplerin pomolojik özellikleri değerlendirildiğinde, meyve ağırlığının 164.50–316.50 g, meyve boyunun 51.81–97.40 mm ve meyve eninin 37.87–54.44 mm arasında değiştiği belirlenmiştir. Genotipler arasındaki farklılıklar kimyasal özelliklerde de belirginleşmiş; asitlik %0.87–2.32, pH 4.31–5.00 ve SÇKM %10.50–14.05 °Brix arasında değişmiştir. Özellikle Pepino Dulce, 316.50 g ile en yüksek meyve ağırlığına ve 2.32 ile en yüksek asitlik değerine sahip olurken, Golden Yellow 97.40 mm ile en uzun meyveleri oluşturmuştur. Natural Mystic ise 14.05 °Brix ile en yüksek SÇKM değerini göstermiş ve bu genotipi tat bakımından öne çıkarmıştır. Meyve eti renk değerleri de genotiplerin birbirinden belirgin şekilde ayrıldığını ortaya koymuş; özellikle a* ve Hue değerlerindeki farklılıkların meyve etinin renk karakterizasyonunda önemli olduğu görülmüştür. Elde edilen bulgular, pitaya genotiplerinin yalnızca meyve büyüklüğü bakımından değil, aynı zamanda renk ve kimyasal kalite özellikleri açısından da geniş bir varyasyon gösterdiğini ortaya koymuştur. Bu farklılıkların, bölgeye uygun genotiplerin belirlenmesi, kalite bakımından üstün materyallerin seçilmesi ve pitaya yetiştiriciliğinin çeşitlendirilmesi açısından önemli bir kaynak oluşturabileceği sonucuna varılmıştır.

Anahtar Kelimeler: *Hylocereus* spp, genotip, meyve kalitesi, meyve rengi, pitaya, pomolojik özellikler.

ABSTRACT

Pitaya (*Hylocereus* spp.) has recently emerged as an important alternative fruit crop due to its distinctive fruit colors, unique morphological characteristics, and attractive quality attributes for consumers. However, the variation among genotypes in terms of fruit size, color characteristics, and chemical composition is an important consideration for cultivation and genotype selection.

Therefore, this study aimed to determine the pomological and selected physicochemical characteristics of different pitaya genotypes. In this context, fruit skin and flesh color characteristics, fruit weight, fruit length, fruit width, titratable acidity, pH, and soluble solids content (SSC) were determined in the Conie Mayer, Pepino Dulce, Philippines Purple, Golden Yellow, and Natural Mystic genotypes. The pomological characteristics varied considerably among the genotypes, with fruit weight ranging from 164.50 to 316.50 g, fruit length from 51.81 to 97.40 mm, and fruit width from 37.87 to 54.44 mm. Differences among genotypes were also evident in their chemical characteristics, with titratable acidity ranging from 0.87 to 2.32%, pH from 4.31 to 5.00, and SSC from 10.50 to 14.05% °Brix. Pepino Dulce had the highest fruit weight (316.50 g) and titratable acidity (2.32%), whereas Golden Yellow produced the longest fruits (97.40 mm). Natural Mystic exhibited the highest SSC value (14.05 °Brix), highlighting its potential in terms of sweetness. Fruit flesh color characteristics also clearly distinguished the genotypes from one another, particularly with respect to a* and Hue values. Overall, the findings demonstrated that pitaya genotypes exhibited substantial variation not only in fruit size but also in color and chemical quality characteristics. These differences may provide valuable opportunities for identifying genotypes adapted to specific growing conditions, selecting superior fruit quality traits, and diversifying pitaya cultivation.
Keywords: Fruit color, fruit quality, *Hylocereus* spp, genotype, pitaya, pomological characteristics

GİRİŞ

Pitaya (*Hylocereus* spp.), Cactaceae familyası içerisinde yer alan ve son yıllarda dünya genelinde üretim ve tüketim potansiyeli giderek artan egzotik meyve türlerinden biridir. Kökeninin Güney ve Orta Amerika olduğu kabul edilen pitaya, zaman içerisinde özellikle Güneydoğu Asya ülkelerine yayılmış ve Vietnam başta olmak üzere önemli bir ticari ürün haline gelmiştir. Dünya pitaya üretiminin 2014 yılında yaklaşık 1 milyon tona ulaştığı bildirilirken, Vietnam günümüzde önemli üretici ve ihracatçı ülkeler arasında yer almaktadır (Mercado-Silva, 2018; Luu ve Le, 2021). Meyvenin kendine özgü görünümü, farklı kabuk ve meyve eti renkleri, hoş tat ve aroması ile fonksiyonel bileşenler bakımından zengin olması, pitayaya olan ilgiyi artırmaktadır. Pitayalarda tür ve çeşitlere bağlı olarak meyve özelliklerinde önemli farklılıklar bulunmaktadır. Kırmızı kabuklu-kırmızı meyve etli, kırmızı kabuklu-beyaz meyve etli ve sarı kabuklu-beyaz meyve etli tipler ticari açıdan en fazla tanınan grupları oluşturmaktadır. Taksonomik çalışmalar sonucunda Hylocereus cinsi içerisinde değerlendirilen bazı türlerin Selenicereus cinsine aktarılmasıyla tür adlandırmalarında değişiklikler meydana gelmiştir. Yaygın materyaller arasında *H. undatus, H. polyrhizus* ve *Selenicereus megalanthus* öne çıkmaktadır (Mercado-Silva, 2018). Bu türler arasında meyve ağırlığı, meyve boyutları, kabuk ve meyve eti rengi ile kimyasal bileşim bakımından önemli farklılıklar bulunmaktadır (Le Bellec ve Vaillant, 2011).

Meyve kalite özellikleri, pitaya çeşitlerinin ticari değerinin belirlenmesinde temel kriterlerden biridir. Meyve ağırlığı, boy, en ve şekil gibi pomolojik özelliklerin yanı sıra kabuk ve meyve eti rengi, SÇKM, pH ve titre edilebilir asitlik tüketici beğenisi ve pazarlanabilirlik açısından önem taşımaktadır. Özellikle meyve renginden sorumlu betalainlerin antioksidan özellikleri ve doğal renklendirici olarak kullanılabilme potansiyeli, pitayayı yalnızca taze tüketim açısından değil, fonksiyonel gıda ve gıda sanayisi açısından da değerli hale getirmektedir (Özer, 2020; Chen ve Xie, 2022). Ayrıca pitaya kabuklarının pektin ve çeşitli biyoaktif bileşenler içermesi, meyvenin farklı endüstriyel alanlarda değerlendirilmesine olanak sağlamaktadır (Reichembach ve Petkowicz, 2021; Kumar vd., 2022).

Pitaya yetiştiriciliğinin yaygınlaştırılmasında en önemli konulardan biri, farklı ekolojik koşullara uyum sağlayabilen ve yüksek meyve kalitesi oluşturan çeşitlerin belirlenmesidir. Bitkinin sıcaklık, ışık, su ve toprak koşullarına verdiği tepki çeşitlere göre değişebilmekte ve bu durum doğrudan meyve verimi ve kalitesi üzerinde etkili olabilmektedir. Özellikle Akdeniz ikliminin hâkim olduğu bölgeler, pitaya yetiştiriciliği açısından önemli bir potansiyel taşımaktadır. Türkiye'de son yıllarda pitaya üretiminin özellikle Akdeniz Bölgesi'nde yaygınlaşmasına rağmen, yöre koşullarında yetiştirilen farklı çeşitlerin meyve kalite özelliklerine ilişkin çalışmaların artırılması gerekmektedir.

Mersin yöresi, sıcaklık ve güneşlenme koşulları bakımından pitaya yetiştiriciliği için uygun ekolojik özelliklere sahip bölgelerden biridir. Ancak aynı ekolojik koşullar altında yetiştirilen çeşitlerin meyve kalite özellikleri bakımından gösterdiği farklılıkların belirlenmesi, üreticilerin çeşit seçiminde ve yüksek kaliteli ürün elde edilmesinde önem taşımaktadır.

Bu nedenle bu çalışmada, Mersin yöresinde yetiştirilen bazı pitaya çeşitlerinin pomolojik ve fizikokimyasal özelliklerinin belirlenmesi amaçlanmıştır. Bu kapsamda çeşitlerin kabuk ve meyve eti renk özellikleri ile meyve ağırlığı, meyve boyu, meyve eni, SÇKM, pH ve asitlik değerleri değerlendirilerek çeşitler arasındaki kalite farklılıklarının ortaya konulması hedeflenmiştir.

MATERYAL VE METOT

Materyal

Bu çalışma Mersin ili, Erdemli ilçesinde üretici bahçesinde temin edilmiştir. Araştırmanın yürütüldüğü bahçe damla sulama sistemi ile sulanmış, budama, gübreleme ve ilaçlama gibi teknik ve kültürel işlemler düzenli olarak yapılmıştır. Çalışmada her çeşitten 3 tekerrürde rastgele seçilen 5'er meyve alınarak ölçümler yapılmıştır.



Şekil 1. Çalışmada kullanılan çeşitler

Metot

Pomolojik özellikleri

Meyve ağırlığı (g) ve çekirdek ağırlığı her bir çeşitten tesadüfen seçilen meyvelerin meyve ağırlığı 0,01 g hassasiyetindeki terazi ile tartımları alınarak tespit edilmiştir (Çulha, 2010).

Meyve boyu (mm), meyve eni (mm), 0.01 mm'ye duyarlı dijital kumpasla ölçülerek ortalama değerleri tespit edilmiştir.

Meyve şekil indeksi ise meyve boyunun meyve çapına bölünmesi ile hesaplanmıştır (Balta ve ark., 2014).

Renk tayini: Çeşit temsil edecek meyvelerden 3 tekerrürde rastgele seçilen 5'er meyvenin kabuk zemin rengi (L,a,b) renk ölçme cihazı (Minolta Co., model CR-400, Tokyo, Japonya) ile belirlenmiştir. Meyvelerin ön (güneş gören) kısmından ölçümler yapılmış, meyve rengi L*, a*, b* cinsinden belirlenmiştir. L*, siyah:0'dan beyaz:100'a olacak şekilde rengin açıklık veya koyuluğu, a* ve b* ise L*'ye dik bir renk düzleminde rengi belirler. Yatay eksende pozitif a* kırmızıyı, negatif a* yeşili; dikey eksendeki pozitif b* sarıyı ve negatif b* ise maviyi göstermektedir. Cihaz, ölçümlerden önce standart beyaz kalibrasyon plakası ile kalibre edilmiştir. Elde edilen a* ve b* değerlerinden rengin doygunluğunu, canlılığını belirleyen Croma (C*) ve rengin temel bileşenlerini (kırmızı, sarı, mavi ve yeşil) belirleyen Hue açısı (ho) değeri hesaplanmıştır.

C*= (a*2+b*2)1/2, ho= tan-1 (b*/a*)

Suda çözünür kuru madde miktarı (SÇKM): Çeşitleri temsil eden meyvelerde SÇKM miktarı meyve suyunda °Brix değeri Dijital refraktometre (Atago, Japan) ile ölçüm yapılmıştır ekranına damlatılmış ve ekranda okunan değer % SÇKM olarak kaydedilmiştir (Uzun ve ark., 2015).

Titre edilebilir asit miktarı: Çeşitleri temsil eden meyve örneklerinden 1 ml meyve suyu alınmış 0,1 N NaOH çözeltisi ile pH 8.1'e gelinceye kadar titre edilmiş ve asitlik malik asit cinsinden % olarak belirlenmiştir (Cemeroğlu, 2007).

Şeker/Asit Oranı: Çeşitleri temsil eden meyve örneklerinde ölçülen SÇKM miktarının Titre edilebilir asite oranlamasıyla tespit edilmiştir.

pH Tayini: Çeşit ait meyve suyu örneklerinden 10 ml meyve suyu alınmış ve dijital pH-metrenin elektrotunun ucu içine daldırılarak pH-metrede değer sabitlenene kadar bekledikten sonra okunan değer pH değeri olarak kaydedilmiştir.

İstatistiksel Analiz

Çalışmada elde edilen pomolojik, fizikokimyasal ve renk özelliklerine ait veriler istatistiksel olarak değerlendirilmiştir. Çeşitler arasındaki farklılıkların belirlenmesi amacıyla tek yönlü varyans analizi (ANOVA) uygulanmıştır. Varyans analizi sonucunda istatistiksel olarak önemli farklılık belirlenen özelliklerde, ortalamalar arasındaki farklılıkların belirlenmesi amacıyla Duncan çoklu karşılaştırma testi kullanılmıştır. İstatistiksel değerlendirmeler %5 önem düzeyinde ($p<0,05$) gerçekleştirilmiş ve sonuçlar ortalama ± standart hata şeklinde verilmiştir. Analizler IBM SPSS Statistics 22 paket programı kullanılarak gerçekleştirilmiştir (Düzgüneş vd., 1987). Renk parametreleri (L*, a*, b*, Croma ve Hue açısı), pomolojik özellikler (meyve ağırlığı, meyve boyu, meyve eni ve şekil indeksi) ve fizikokimyasal özellikler (SÇKM, pH, titre edilebilir asitlik ve şeker/asit oranı) ayrı ayrı analiz edilmiştir.

BULGULAR VE TARTIŞMA

İncelenen pitaya çeşitleri, kabuk rengi bakımından oldukça belirgin farklılıklar göstermiştir. L* değeri meyve kabuğunun açıklık-koyuluğunu ifade etmekte olup çeşitler arasında 36,96–63,24 arasında değişmiştir. En yüksek L* değeri 63,24 ile Golden Yellow çeşidinde belirlenirken, bunu Pepino Dulce (47,22) izlemiştir. En düşük L* değerleri ise Philippines Purple (36,96), Macenta (39,74) ve Natural Mystic (40,42) çeşitlerinde belirlenmiştir (Tablo 1). Golden Yellow çeşidinin diğer çeşitlerden belirgin biçimde yüksek L* değerine sahip olması, bu çeşidin daha açık renkli bir kabuk yapısına sahip olduğunu göstermektedir. Nitekim bu çeşitte a* değerinin -1,31 ve b* değerinin 23,05 olması, kabuk renginin kırmızı tonlardan ziyade sarı tonlara yöneldiğini ortaya koymaktadır (Tablo 1). Buna karşılık Philippines Purple, Macenta ve Natural Mystic çeşitlerinde pozitif a* değerleri, kabuk renginde kırmızı tonların baskın olduğunu göstermiştir. Kabuk renginin kromatik özellikleri değerlendirildiğinde, Croma değerleri 23,09–31,36 arasında değişmiş ve en yüksek değer Natural Mystic çeşidinde (31,36) belirlenmiştir (Tablo 1). Bu durum Natural Mystic çeşidinin daha doygun ve belirgin bir kabuk rengine sahip olduğunu göstermektedir. Golden Yellow çeşidinde ise Croma değerinin 23,09 ile diğer çeşitlere göre daha düşük olması, kabuğun sarı tonunun daha düşük renk doygunluğu ile ortaya çıktığını düşündürmektedir. Hue açısı bakımından ise Golden Yellow 93,29 ile diğer çeşitlerden tamamen ayrılmış ve sarı renk karakterini açık biçimde ortaya koymuştur. Buna karşılık Natural Mystic'in 2,93, Philippines Purple'ın 7,28 ve Pepino Dulce'nin 5,94 değerleri kırmızı tonların baskın olduğu kabuk renklenmesini göstermiştir (Tablo 1). Bu sonuçlar, renk ölçümlerinin çeşitlerin görsel olarak birbirinden ayrılmasında önemli bir kalite kriteri olduğunu ortaya koymaktadır.

Çalışmamızda elde edilen sonuçlar literatürde bildirilen pitaya renk değerleriyle karşılaştırıldığında, çeşit ve türler arasında önemli farklılıklar bulunduğu görülmektedir. Cordeiro vd. (2015), Brezilya'nın Janaúba bölgesinde yetiştirilen kırmızı pitayada kabuk L* değerini 42,75 olarak bildirmiştir. Bu değer, çalışmamızda kırmızı kabuk karakteri gösteren Philippines Purple (36,96), Macenta (39,74), Natural Mystic (40,42) ve Pepino Dulce (47,22) çeşitlerinde belirlenen değerler arasında yer almaktadır. Özellikle Pepino Dulce'nin L* değeri (47,22), Cordeiro vd. (2015)'nin bildirdiği değerden daha yüksek olurken, diğer üç çeşidin değerleri daha düşük bulunmuştur. Bu farklılığın genetik yapı, yetiştirme koşulları, meyve olgunluk düzeyi ve ölçüm yapılan meyve materyalindeki farklılıklardan kaynaklanabileceği düşünülmektedir. Esquivel vd. (2007), Kosta Rika'da yetiştirilen beş farklı H. *polyrhizus* çeşidinde L*, a* ve b* değerlerinin sırasıyla 6,0–8,1, 31,7–35,9 ve -1,57–2,0 arasında değiştiğini bildirmiştir. Araştırıcılar çeşitler arasındaki renk farklılıklarının önemli ölçüde betalain pigmentlerinin miktarı ve dağılımıyla ilişkili olduğunu belirtmiştir. Çalışmamızda Natural Mystic çeşidinin a* değeri 31,32 ile bu çalışmada bildirilen aralığa oldukça yakın bulunmuştur. Pepino Dulce'nin a* değeri (29,77) ise bu aralığa yakın bir değer gösterirken, Philippines Purple (26,77) ve Macenta (24,54) daha düşük değerler vermiştir.

Bununla birlikte çalışmamızda L* değerlerinin Esquivel vd. (2007)'nin bildirdiği değerlerden belirgin biçimde yüksek olması, materyal ve ölçüm koşullarındaki farklılıkların renk değerleri üzerindeki etkisini ortaya koymaktadır.

Angonese vd. (2021), *H. polyrhizus* meyvesinde L*, a* ve b* değerlerini sırasıyla 21,82, 6,67 ve 0,68; H. undatus meyvesinde ise 55,30, 1,22 ve 2,17 olarak bildirmiştir. Araştırıcılar H. polyrhizus'un daha koyu ve kırmızı renk karakterinin betalain pigmentleriyle ilişkili olduğunu, yüksek pigment birikiminin L* değerinin düşmesine ve renk özelliklerinin değişmesine neden olduğunu belirtmiştir. Çalışmamızda da kırmızı renkli çeşitler arasında daha düşük L* değerlerinin bulunması genel olarak bu yaklaşımla uyumludur. Bununla birlikte çalışmamızda Natural Mystic'in a* değerinin 31,32 gibi yüksek bir değere ulaşması, kırmızı renk yoğunluğunun belirgin olduğunu göstermektedir. Balcı, (2025) Muğla bölgesinde yetiştirilen Vietnam White ve Siam Red pitaya çeşitlerinin pomolojik ve biyokimyasal özelliklerini belirlemek amacıyla yürütülmüştür. Araştırmada Vietnam White çeşidinin kabuk L* değeri 41.54, a* değeri 35.37 ve b* değeri 11.03; meyve eti L* değeri 74.62, a* değeri 10.22 ve b* değeri 4.33 olarak belirlenmiştir. Siam Red çeşidinde ise kabuk L*, a* ve b* değerleri sırasıyla 39.70, 37.74 ve 13.35; meyve eti L*, a* ve b* değerleri sırasıyla 33.67, 45.73 ve-2.14 olarak tespit edilmiştir. Yılmaz ve Ersus (2023), Antalya koşullarında yetiştirilen kırmızı pitayalarda L*, a* ve b* değerlerini sırasıyla 6,44, 35,11 ve -5,70 olarak bildirmiştir. Çalışmamızdaki Natural Mystic çeşidinin a* değeri (31,32), söz konusu çalışmada bildirilen 35,11 değerine yakın bulunmuştur. Buna karşın L* ve b* değerlerinin çalışmamızdan farklı olması, pitayada renk özelliklerinin yalnızca tür ve çeşide değil, aynı zamanda ekolojik koşullara, yetiştirme uygulamalarına, meyve olgunluğuna ve ölçüm yapılan dokuya bağlı olarak değişebildiğini göstermektedir. Angonese vd. (2021) ve Esquivel vd. (2007)'nin bulguları birlikte değerlendirildiğinde, kırmızı meyve karakterinin oluşumunda betalain pigmentlerinin önemli rol oynadığı görülmektedir. Çalışmamızda özellikle Natural Mystic, Pepino Dulce ve Philippines Purple çeşitlerinde yüksek pozitif a* değerlerinin bulunması, bu çeşitlerde kırmızı renk bileşeninin baskın olduğunu ortaya koymaktadır. Buna karşılık Golden Yellow çeşidinin negatif a* (-1,31), yüksek b* (23,05) ve çok yüksek Hue (93,29) değerleri, bu çeşidin renk karakterinin diğer materyallerden tamamen farklı olduğunu ve sarı tonların baskın olduğunu göstermektedir. Dolayısıyla renk parametreleri, incelenen genotiplerin görsel olarak birbirinden ayrılmasında oldukça başarılı bir gösterge olmuştur.

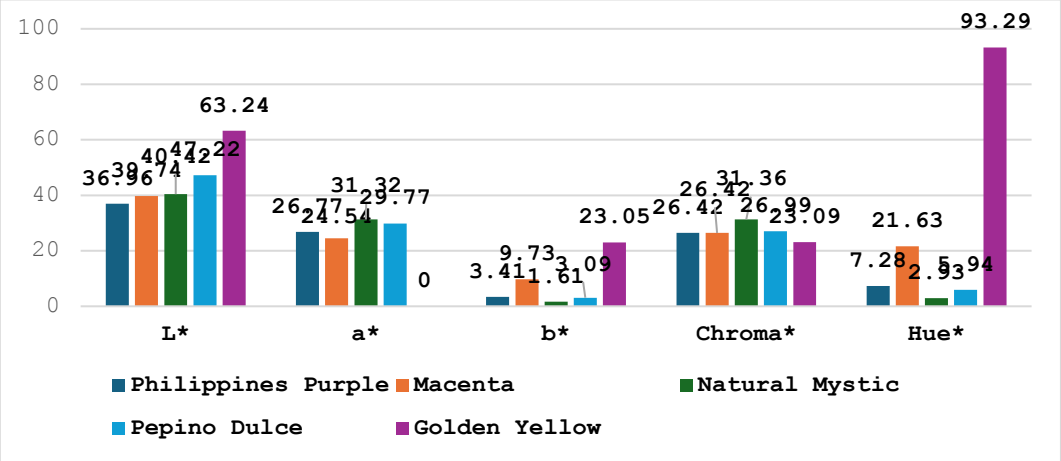
Pitaya renk özelliklerinin değerlendirilmesinde renk pigmentlerinin yanı sıra meyvenin biyokimyasal bileşimi de önem taşımaktadır. Luu vd. (2021), pitaya meyvesinin fenolik bileşikler, flavonoidler, askorbik asit ve betalainler bakımından zengin olduğunu ve bu bileşiklerin meyvenin antioksidan özelliklerine katkı sağladığını bildirmiştir. Kumar vd. (2022) ise flavonoidlerin önemli miktarda meyve kabuğunda bulunabildiğini ve pitaya kabuğunun yüksek pektin içeriğine sahip olduğunu belirtmiştir. Muhammad vd. (2014) tarafından *H. polyrhizus* kabuğundan elde edilen pektinde mannoz, ramnoz, galaktoz, glikoz, ksiloz, arabinoz ve galakturonik asit gibi bileşenlerin belirlenmiş olması, pitaya kabuğunun fonksiyonel ve endüstriyel açıdan değerlendirilebilecek önemli bir yan ürün olduğunu göstermektedir.

Genel olarak, çalışmamızda elde edilen kabuk renk sonuçları literatürde bildirilen değerlerle bazı farklılıklar göstermekle birlikte, kırmızı renk yoğunluğu ile a değerleri ve renk doygunluğu ile Croma değerleri arasındaki ilişki açısından literatürle benzer eğilimler ortaya koymuştur*. Özellikle Natural Mystic çeşidinin yüksek a* (31,32) ve Croma (31,36) değerleri, bu çeşidin belirgin ve doygun kırmızı kabuk rengine sahip olduğunu göstermektedir. Golden Yellow ise yüksek L* (63,24), yüksek b* (23,05) ve Hue (93,29) değerleriyle tamamen farklı bir sarı renk karakteri ortaya koymuştur. Bu farklılıkların, çeşitlerin genetik yapısına bağlı pigment kompozisyonunun yanı sıra yetiştirme koşulları ve meyve olgunluk düzeyinden etkilenmiş olabileceği düşünülmektedir. Ayrıca renk özelliklerinin tüketici tercihi açısından önemli duyusal özellikler arasında yer alması (Bilek, 2010), çalışmada belirlenen renk farklılıklarının yalnızca taksonomik veya fiziksel bir özellik olmadığını, aynı zamanda pazarlama ve tüketici kabulü açısından da önemli olduğunu göstermektedir.

Tablo 1. L*,a*,b* renk ölçümleri sonuçları

Çeşitler	L*	a*	b*	Chroma*	Hue*
Philippines Purple	36,96±2.91c	26,77±0.61b	3,41±0.33c	26,42±0.57bc	7,28±0.84c
Macenta	39,74±1.55c	24,54±0.39c	9,73±0.82b	26,42±0.06cd	21,63±1.97b
Natural Mystic	40,42±0.24c	31,32±0.82a	1,61±0.02c	31,36±0.82a	2,93±0.02d
Pepino Dulce	47,22±0.15b	29,77±0.66a	3,09±0.38c	26,99±0.66ab	5,94±0.76cd
Golden Yellow	63,24±1.91a	-1,31±0.27d	23,05±1.93a	23,09±1.92d	93,29±0.84a

Aynı harfle gösterilen ortalamalar arasındaki fark istatistiksel olarak önemli değildir ($p < 0,05$).



Şekil 2. Çeşitlere ait L*,a*, b*, Chroma*, Hue* grafiği

Pomolojik özellikler değerlendirildiğinde çeşitler arasında önemli farklılıklar belirlenmiştir. Meyve ağırlığı 164,50–316,50 g arasında değişmiş ve en yüksek değer Pepino Dulce çeşidinde 316,50 g olarak belirlenmiştir. Bu çeşidi Philippines Purple (253,00 g) ve Golden Yellow (221,00 g) izlemiştir. En düşük meyve ağırlığı ise 164,50 g ile Natural Mystic çeşidinde saptanmıştır (Tablo 2). Pepino Dulce'nin meyve ağırlığı bakımından diğer çeşitlerden ayrılması, bu çeşidin ticari açıdan özellikle iri meyve özelliği bakımından dikkat çekici olduğunu göstermektedir. Le Bellec ve Vaillant (2011), pitaya çeşitlerinde meyve ağırlığının genetik yapı ve çeşide bağlı olarak önemli ölçüde değişebildiğini bildirmiştir. Bu çalışmada elde edilen sonuçlar da çeşitler arasındaki genetik farklılığın meyve büyüklüğüne yansıdığını desteklemektedir. Meyve boyu bakımından en yüksek değer Golden Yellow çeşidinde 97,40 mm olarak belirlenmiş ve bu çeşit diğer çeşitlerden istatistiksel olarak ayrılmıştır. En düşük meyve boyu ise 51,81 mm ile Natural Mystic çeşidinde saptanmıştır. Bununla birlikte meyve eni açısından en yüksek değer 54,44 mm ile Pepino Dulce'de, en düşük değer ise 37,87 mm ile Golden Yellow'da belirlenmiştir. Bu sonuç, Golden Yellow çeşidinin yüksek meyve boyuna karşın daha dar meyveler oluşturduğunu göstermektedir. Nitekim meyve şekil indeksi Golden Yellow'da 2,58 ile en yüksek değere ulaşırken, Natural Mystic'te 1,05 olarak belirlenmiş ve bu çeşit daha yuvarlak bir meyve formu göstermiştir. Dolayısıyla çeşitler arasındaki farklılık yalnızca meyve büyüklüğü ile sınırlı kalmamış, meyve morfolojisinin de önemli ölçüde değiştiği görülmüştür. Paull (2002), pitaya meyvelerinin uluslararası düzeyde standart bir sınıflandırmasının bulunmadığını, ancak Vietnam'da meyve ağırlığına göre 500 g ve üzerindeki meyvelerin ekstra büyük, 380–500 g arasındaki meyvelerin büyük, 300–380 g arasındakilerin normal, 260–300 g arasındakilerin orta ve 260 g'ın altındaki meyvelerin küçük olarak değerlendirildiğini bildirmiştir. Bu sınıflandırma dikkate alındığında, çalışmamızda yalnızca Pepino Dulce çeşidi 316,50 g ile normal meyve sınıfında yer alırken, Philippines Purple (253,00 g), Golden Yellow (221,00 g), Macenta (204,50 g) ve Natural Mystic (164,50 g) küçük meyve sınıfında değerlendirilmiştir. Bununla birlikte, bu sınıflandırmanın Vietnam koşullarında kullanılan bir değerlendirme yaklaşımı olduğu ve farklı ülkelerde yetiştirilen materyallerin doğrudan bu sınır değerlerle değerlendirilmesinin dikkatli yapılması gerektiği göz önünde bulundurulmalıdır.

Cordeiro vd. (2015), Brezilya'nın Janaúba bölgesinde yetiştirilen kırmızı pitayalarda ortalama meyve ağırlığını 411,22 g, meyve uzunluğunu ise 107,06 mm olarak bildirmiştir. Çalışmamızdaki tüm çeşitlerin meyve ağırlıkları ve meyve boyları bu değerlerin altında kalmıştır. En yüksek meyve ağırlığına sahip Pepino Dulce'de 316,50 g, en uzun meyveye sahip Golden Yellow'da ise 97,40 mm değerleri belirlenmiştir. Benzer şekilde Le Bellec vd. (2011), *H. monocanthus* (*H. polyrhizus*) meyvelerinin genellikle 10–15 cm uzunluğunda ve 200–400 g ağırlığında olduğunu bildirmiştir. Çalışmamızda Philippines Purple'ın meyve ağırlığı 253,00 g ve meyve boyu 74,39 mm olarak belirlenmiş olup ağırlık bakımından bu aralık içerisinde, ancak meyve boyu bakımından bildirilen aralığın altında kalmıştır. Bu farklılıklar; çeşit/genotip, ekolojik koşullar, yetiştirme uygulamaları, bitkinin yaşı, tozlanma başarısı ve hasat olgunluğu gibi faktörlerin meyve büyüklüğü üzerinde etkili olabileceğini düşündürmektedir.

Meyve boyu bakımından çeşitler arasında dikkat çekici bir farklılık belirlenmiştir. En uzun meyveler 97,40 mm ile Golden Yellow çeşidinde, en kısa meyveler ise 51,81 mm ile Natural Mystic çeşidinde saptanmıştır (Tablo 2). Golden Yellow'ın meyve ağırlığı 221,00 g olmasına rağmen meyve boyunda ilk sırada yer alması, bu çeşidin daha uzun ve ince bir meyve morfolojisine sahip olduğunu göstermektedir. Nitekim bu durum meyve eni ve şekil indeksi değerleriyle de desteklenmektedir. Golden Yellow'da meyve eni 37,87 mm ile en düşük değerlerden biri olurken, meyve şekil indeksi 2,58 ile tüm çeşitler arasında en yüksek değere ulaşmıştır. Dolayısıyla Golden Yellow, çalışmada uzun ve nispeten dar meyve formuyla karakterize edilen çeşit olarak öne çıkmıştır. Buna karşılık Pepino Dulce, 316,50 g ile en yüksek meyve ağırlığına ve 54,44 mm ile en yüksek meyve eni değerine sahip olmuştur. Meyve boyunun 74,14 mm olmasıyla birlikte değerlendirildiğinde, Pepino Dulce'nin Golden Yellow'a kıyasla daha dolgun ve geniş meyve yapısına sahip olduğu görülmektedir. Meyve şekil indeksinin 1,36 olması da bu durumu desteklemekte ve meyvenin daha kısa-geniş bir forma sahip olduğunu göstermektedir. Natural Mystic ise 164,50 g meyve ağırlığı, 51,81 mm meyve boyu ve 49,26 mm meyve eni ile daha küçük fakat daha yuvarlak bir meyve yapısı sergilemiştir. Bu çeşitte şekil indeksinin 1,05 olması, boy ve en değerlerinin birbirine oldukça yakın olduğunu ve meyvenin yuvarlak forma yaklaştığını göstermektedir.

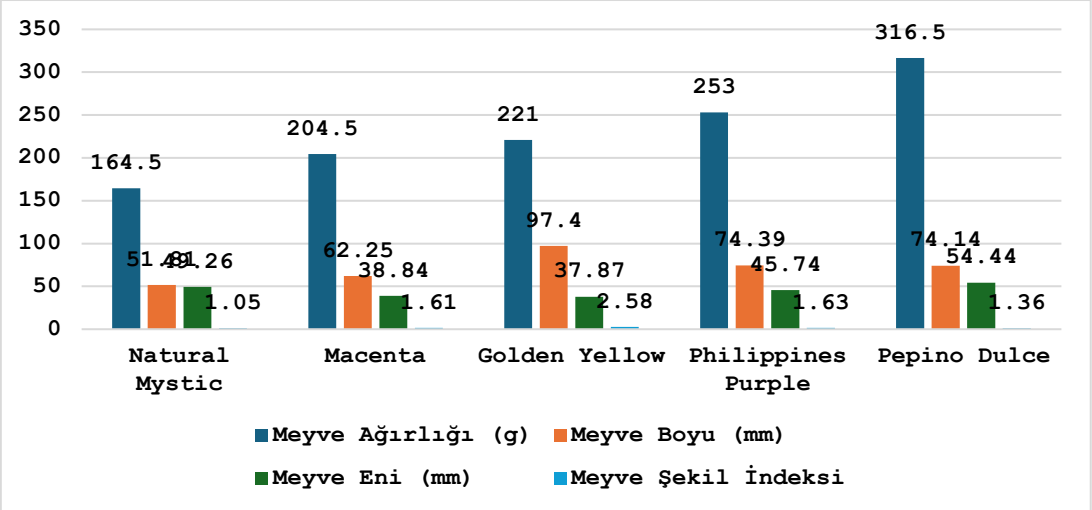
Meyve eni bakımından en yüksek değer Pepino Dulce'de (54,44 mm), en düşük değer ise Golden Yellow'da (37,87 mm) belirlenmiştir (Tablo 2). Philippines Purple (45,74 mm) ve Natural Mystic (49,26 mm) orta düzeyde değerler gösterirken, Macenta 38,84 mm ile Golden Yellow'a yakın bir meyve eni oluşturmuştur. Bu sonuçlar, meyve ağırlığının yalnızca meyve boyuyla açıklanamayacağını, meyvenin eninin ve dolayısıyla genel şeklinin de meyve ağırlığı üzerinde önemli rol oynadığını göstermektedir.

Genel olarak değerlendirildiğinde, çalışmada incelenen çeşitler pomolojik özellikleri bakımından üç farklı karakter ortaya koymuştur. Pepino Dulce, yüksek meyve ağırlığı ve meyve eni ile iri ve dolgun meyve yapısıyla öne çıkarken; Golden Yellow, yüksek meyve boyu ve şekil indeksi ile uzun ve ince meyve karakteri göstermiştir. Natural Mystic ise düşük meyve ağırlığı ve boyuna rağmen düşük şekil indeksi ile daha yuvarlak meyveler oluşturmuştur. Philippines Purple ve Macenta ise bu iki karakter arasında daha dengeli pomolojik özellikler sergilemiştir.

Tablo 2. Çeşitlere ait pomolojik ölçümlerin sonuçları

Çeşitler	Meyve Ağırlığı (g)	Meyve Boyu (mm)	Meyve Eni (mm)	Meyve Şekil İndeksi
Natural Mystic	164,50±12.28c	51,81±9.96c	49,26±7.28ab	1,05±0.03c
Macenta	204,50±15.92bc	62,25±1.01bc	38,84±2.29b	1,61±0.12b
Golden Yellow	221,00±4.02b	97,40±1.93a	37,87±1.28b	2,58±0.13a
Philippines Purple	253,00±2.44b	74,39±0.71b	45,74±1.57ab	1,63±0.07b
Pepino Dulce	316,50±28.98a	74,14±0.04b	54,44±1.88a	1,36±0.04b

Aynı harfle gösterilen ortalamalar arasındaki fark istatistiksel olarak önemli değildir ($p < 0,05$).



Şekil 3. Çeşitlere ait pomolojik ölçümlerin grafiği

SÇKM Titre edilebilir Asitlik ve pH özellikleri

Sonuçlar değerlendirildiğinde, çeşitler arasında belirgin farklılıklar olduğu görülmüştür. Titre edilebilir asitlik (TEA) değerleri %0,87–2,32 arasında değişmiş ve en yüksek değer %2,32 ile Pepino Dulce çeşidinde, en düşük değer ise %0,87 ile Macenta çeşidinde belirlenmiştir (Tablo 2). Natural Mystic (%0,88) çeşidi Macenta'e oldukça yakın bir asitlik değeri gösterirken, Philippines Purple (%1,10) ve Golden Yellow (%2,19) çeşitleri daha yüksek asitlik değerlerine sahip olmuştur. Bu farklılıklar, çeşitlerin tat karakterinin yalnızca çözünür kuru madde miktarıyla değil, aynı zamanda organik asit düzeyi ve dolayısıyla şeker/asit dengesiyle de şekillendiğini göstermektedir.

pH değerleri 4,31–5,00 arasında değişmiş; en yüksek değer Natural Mystic çeşidinde (5,00), en düşük değer ise Pepino Dulce çeşidinde (4,31) belirlenmiştir (Tablo 3). pH ve TEA değerleri birlikte değerlendirildiğinde, Pepino Dulce ve Golden Yellow çeşitlerinin daha yüksek asitlik düzeyleriyle, Natural Mystic çeşidinin ise düşük asitlik ve yüksek pH değeriyle ayrıldığı görülmektedir. Özellikle Natural Mystic'te belirlenen düşük TEA ve yüksek pH değeri, bu çeşidin daha düşük asidite algısına sahip olabileceğini düşündürmektedir.

Suda çözünür kuru madde (SÇKM) bakımından da çeşitler arasında önemli farklılıklar belirlenmiştir. En yüksek SÇKM değeri %14,05 ile Natural Mystic çeşidinde belirlenmiş, bunu Philippines Purple (%12,10) ve Macenta (%12,00) çeşitleri izlemiştir (Tablo 3). En düşük değer ise %10,50 ile Golden Yellow çeşidinde saptanmıştır. Natural Mystic çeşidinin yüksek SÇKM değerinin düşük asitlik ile birlikte bulunması, bu çeşidin tüketim açısından daha tatlı ve dengeli bir tat profiline sahip olabileceğini göstermektedir. Merten (2003), pitaya meyvelerinde yaklaşık %12–13 düzeyindeki Brix değerlerinin tüketim olgunluğu açısından önemli bir gösterge olduğunu bildirmiştir. Bu açıdan değerlendirildiğinde, Natural Mystic (%14,05), Macenta (%12,00) ve Philippines Purple (%12,10) çeşitlerinin SÇKM bakımından olgunluk ve tüketim kalitesi açısından dikkat çekici olduğu söylenebilir. Buna karşılık Golden Yellow çeşidinin %10,50 ile daha düşük SÇKM değerine sahip olması, yüksek asitlik değeriyle birlikte değerlendirildiğinde daha belirgin bir ekşi tat profiline işaret etmektedir.

Şeker/asit oranı, meyvenin tatlılık ve asitlik arasındaki dengesini değerlendirmede önemli bir kriterdir. Çalışmada bu değer 4,80–15,91 arasında değişmiş ve en yüksek oran Natural Mystic çeşidinde (15,91), en düşük oran ise Golden Yellow çeşidinde (4,80) belirlenmiştir (Tablo 3). Natural Mystic'in yüksek SÇKM (%14,05), düşük TEA (%0,88) ve yüksek şeker/asit oranını birlikte göstermesi, bu çeşidin tat dengesi bakımından öne çıkan bir materyal olduğunu ortaya koymaktadır. Buna karşılık Pepino Dulce çeşidinde yüksek meyve ağırlığı ve meyve eni ile birlikte yüksek TEA (%2,32) değerinin belirlenmesi, bu çeşidin pomolojik açıdan iri, ancak tat profili bakımından daha asidik bir karakter taşıdığını göstermektedir. Dolayısıyla çeşitlerin değerlendirilmesinde tek bir kalite parametresinden ziyade, meyve iriliği, SÇKM, asitlik, pH ve şeker/asit oranının birlikte ele alınması daha anlamlıdır.

Literatür bulguları değerlendirildiğinde, çalışmamızda belirlenen SÇKM değerlerinin pitaya için daha önce bildirilen değerlerle genel olarak uyumlu olduğu görülmektedir.

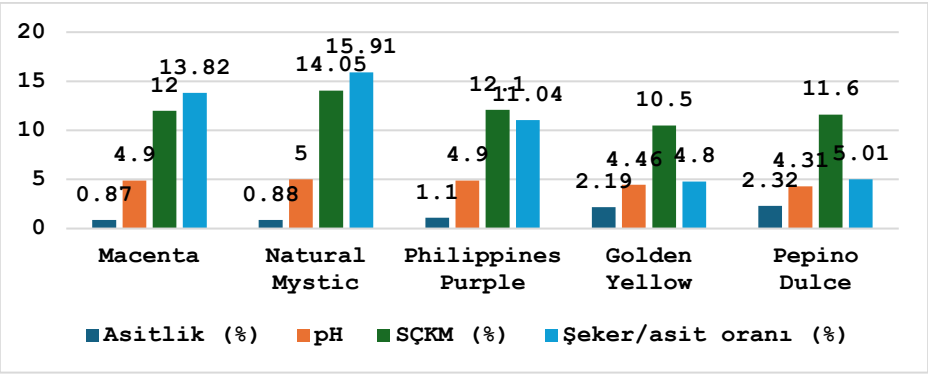
Cordeiro vd. (2015), Brezilya'nın Janaúba bölgesinde yetiştirilen kırmızı pitaya meyvelerinde SÇKM miktarını ortalama %13,14 ve pH değerini 5,32 olarak bildirmiştir. Bu değerle karşılaştırıldığında, çalışmamızdaki Natural Mystic (%14,05) çeşidinin SÇKM değeri daha yüksek, Macenta (%12,00) ve Philippines Purple (%12,10) çeşitlerinin değerleri ise benzer düzeydedir. Golden Yellow (%10,50) ve diğer düşük SÇKM değerine sahip materyaller ise Cordeiro vd. (2015)'nin bildirdiği değerin altında kalmıştır. Bu farklılıkların genotip, yetiştirme koşulları, hasat olgunluğu, sulama ve besleme uygulamaları gibi faktörlerden kaynaklanabileceği düşünülmektedir. Angonese vd. (2021), aynı yetiştirme koşullarında *Hylocereus undatus* ve *H. polyrhizus* türlerini karşılaştırmış ve *H. polyrhizus* meyvelerinde pH değerini 4,77 ± 0,02, TEA değerini ise 273,71 ± 7,66 mg malik asit/100 g olarak belirlemiştir. H. undatus meyvelerinde ise pH 4,24 ± 0,02 ve TEA 491,45 ± 36,26 mg malik asit/100 g olarak bildirilmiştir. Bu sonuçlar, türler arasında özellikle TEA bakımından önemli farklılıklar bulunabildiğini göstermektedir. Çalışmamızda belirlenen pH değerlerinin 4,31–5,00 arasında değişmesi, bu literatür değerleriyle genel olarak örtüşmekte ve pitayada pH'nın genetik yapı ve yetiştirme koşullarına bağlı olarak değişebildiğini desteklemektedir. Balcı, (2025), Muğla bölgesinde yetiştirilen Vietnam White ve Siam Red pitaya çeşitlerinin pomolojik ve biyokimyasal özelliklerini belirlemek amacıyla yürütülmüştür. Araştırmada Vietnam White çeşidinde suda çözünebilir kuru madde oranı %12.57, pH 4.46 ve titre edilebilir asitlik oranı %0.36 olarak belirlenmiştir. Siam Red çeşidinde ise sırasıyla %10.94, 4.60 ve %0.45 olarak saptanmıştır. Yılmaz ve Ersus (2023) ise Antalya koşullarında yetiştirilen kırmızı pitayalarda (*H. polyrhizus*) pH değerlerinin 4,97–5,13 arasında değiştiğini bildirmiştir. Çalışmamızda Natural Mystic çeşidinde belirlenen 5,00 pH değeri bu aralıkla oldukça yakın bulunurken, diğer çeşitlerde belirlenen değerlerin bir kısmı daha düşük düzeyde kalmıştır. Bu durum, aynı tür veya yakın genetik gruplar içerisinde dahi meyve kimyasal özelliklerinin yetiştirme ekolojisi ve genotipe bağlı olarak değişebileceğini göstermektedir.

Genel olarak değerlendirildiğinde, çalışmamızda çeşitler arasında belirlenen SÇKM, pH, TEA ve şeker/asit oranındaki farklılıklar, genotiplerin yalnızca fiziksel özellikler bakımından değil, tüketim kalitesi ve tat profili bakımından da önemli ölçüde farklılaştığını ortaya koymaktadır. Özellikle Natural Mystic, yüksek SÇKM, düşük asitlik, yüksek pH ve yüksek şeker/asit oranını birlikte göstermesi nedeniyle kimyasal ve duyusal kalite açısından; Pepino Dulce ise yüksek meyve ağırlığı ve meyve eni bakımından öne çıkmaktadır. Bu nedenle söz konusu genotiplerin farklı kullanım amaçları açısından değerlendirilmesi ve özellikle Natural Mystic'in doğrudan tüketime yönelik kalite bakımından ileri çalışmalarla değerlendirilmesi önerilebilir.

Tablo 3. Çeşitlere ait bazı pomolojik özelliklerin sonuçları

Çeşitler	Asitlik (%)	pH	SÇKM (%)	Şeker/asit oranı
Macenta	0,87±0.00e	4,90±0.00b	12,00±0.08b	13,82±0.05b
Natural Mystic	0,88±0.00d	5,00±0.00a	14,05±0.04a	15,91±0.15a
Philippines Purple	1,10±0.00c	4,90±0.00b	12,10±0.08b	11,04±0.04c
Golden Yellow	2,19±0.00b	4,46±0.00c	10,50±0.08d	4,80±0.04d
Pepino Dulce	2,32±0.00a	4,31±0.00d	11,60±0.08c	5,01±0.02d

Aynı harfle gösterilen ortalamalar arasındaki fark istatistiksel olarak önemli değildir ($p < 0,05$).



Şekil 5. Çeşitlere ait kimyasal özelliklerin grafiği

Tablo 4. Pitaya çeşitlerinin meyve iriliği ve kalite özelliklerine göre genel performanslarının değerlendirilmesi

Çeşit	Meyve İriliği / Potansiyel Verim*	Meyve Kalitesi	Öne Çıkan Özellik	Genel Değerlendirme
Pepino Dulce	★★★★★	★★★★☆	En yüksek meyve ağırlığı (316,50 g), yüksek meyve eni	İri meyve ve ticari üretim açısından güçlü
Natural Mystic	★★☆☆☆	★★★★★	En yüksek SÇKM (%14,05), şeker/asit oranı (15,91), yüksek kırmızılık	Üstün iç kalite ve tat potansiyeli
Philippines Purple	★★★★☆	★★★★☆	253 g meyve ağırlığı, dengeli kalite	Dengeli meyve iriliği ve kalite
Macenta	★★★☆☆	★★★★☆	Orta meyve ağırlığı, düşük asitlik (%0,87)	Dengeli ve tatlı meyve karakteri
Golden Yellow	★★★☆☆	★★★☆☆	En uzun meyve (97,40 mm), karakteristik sarı renk	Farklı görünüm ve özel pazar potansiyeli

Not: "Potansiyel verim" değerlendirmesi doğrudan verim ölçümüne değil, mevcut verilerdeki meyve ağırlığı ve meyve büyüklüğüne dayanmaktadır.

Değerlendirme Alanı	Öne Çıkan Çeşitler
Meyve iriliği / ticari potansiyel	1. Pepino Dulce → 2. Philippines Purple
Tat ve iç kalite	1. Natural Mystic → 2. Macenta
Görsel kalite / kırmızı renk	1. Natural Mystic → 2. Pepino Dulce
Özel pazar ve farklılık	Golden Yellow
Genel kalite potansiyeli	Natural Mystic ve Pepino Dulce

SONUÇ VE ÖNERİLER

Genel olarak değerlendirildiğinde, çeşitlerin tek bir kalite kriteri bakımından üstünlük göstermediği, farklı özellikler açısından farklı avantajlara sahip olduğu görülmektedir. Pepino Dulce yüksek meyve ağırlığı ve meyve eni ile iri meyveli bir materyal olarak öne çıkarken, Golden Yellow uzun ve belirgin sarı kabuk rengiyle farklı bir görsel karakter sergilemiştir. Philippines Purple orta-yüksek meyve ağırlığı ve kırmızı renk karakteriyle dikkat çekerken, Macenta dengeli pomolojik ve kimyasal özellikler göstermiştir. Buna karşılık Natural Mystic; yüksek SÇKM, düşük asitlik, yüksek pH ve özellikle yüksek şeker/asit oranı ile tat kalitesi bakımından öne çıkmıştır. Bu sonuçlar, Mersin yöresinde pitaya çeşitlerinin değerlendirilmesinde yalnızca meyve iriliğinin değil, renk, meyve şekli ve kimyasal bileşimin birlikte ele alınmasının daha doğru bir çeşit değerlendirme yaklaşımı sağlayacağını ortaya koymaktadır. Bu çeşitlerin Mersin koşullarındaki performanslarının farklı yıllarda verim, kalite, hasat zamanı ve tüketici beğenisi yönünden birlikte değerlendirilmesi önerilmektedir.

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BAZI ÇOK YILLIK BAKLAGİL YEM BİTKİLERİ TÜRLERİNDE DÜŞÜK SICAKLIĞIN TOHUM ÇİMLENMESİ ÜZERİNE ETKİSİ

THE EFFECT OF LOW TEMPERATURE ON SEED GERMINATION IN SOME PERENNIAL FORAGE LEGUMES

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ÖZET
Farklı düşük sıcaklıklarda bazı çok yıllık baklagil yem bitkileri türlerinde tohum çimlenme özelliklerinin belirlenmesi amacıyla yürütülmüştür. Araştırmada baklagiller *(Fabaceae)* familyasından ak üçgül (*Trifolium repens*), çayır üçgülü (*T. pratense*), gazal boynuzu (*Lotus corniculatus*) ve yaygın yonca (*Medicago sativa*) türlerine ait tohumlar, laboratuvar şartlarında 2, 4, 6, 8 ve 10 °C sıcaklıkta 4 tekrarlamalı olarak çimlendirilmiştir. Tohumlar 20 gün süreyle çimlendirilmeye bırakılmış ve 24 saat arayla çimlenen tohumlar belirlenmiştir. Çalışma sonunda çimlenme oranı, çimlenme potansiyeli ve ortalama çimlenme süresi belirlenmiştir. Elde edilen veriler her bir tür için ayrı ayrı değerlendirilmiştir. Verilere varyans analizi öncesinde Shapiro-Wilk ve Levene testleri uygulanmış, ardından gerekli durumlarda transformasyonlar yapılarak Tesadüf parselleri deneme deseninde varyans analizi veya t testi uygulanmıştır. Ortalamalar arasındaki farklılıklar Tukey çoklu karşılaştırma testi ile belirlenmiştir. Yapılan istatistik analizi sonucunda, düşük sıcaklık değerlerinin her bir türde tohumların çimlenme oranı, çimlenme potansiyeli ve ortalama çimlenme süresi üzerinde istatistiki olarak önemli etkisinin olduğu belirlenmiştir. Araştırmada gazal boynuzu tohumları 2 °C'de çimlenmezken, diğer türlerde 2 °C'de çimlenme gerçekleşmiştir. Sıcaklık artışı ile birlikte türlerde çimlenme oranı da artırmıştır. Ak üçgül 10 °C'de, çayır üçgülü ise 8 °C'de % 100 çimlenmiştir. Aynı zamanda sıcaklık arttıkça ortalama çimlenme süresi ve çimlenme başlangıcı da kısalmıştır. İncelenen bütün türlerde en kısa ortalama çimlenme süresi, 10 °C'de belirlenmiştir.
Anahtar Kelimeler: Tohum, Çimlenme, Sıcaklık

ABSTRACT
It was carried out to determine the seed germination characteristics of some perennial forage grass at different low temperatures. In the study, seeds belonging to the white clover (*Trifolium repens*), red clover (*T. pratense*), birdsfoot trefoil (*Lotus corniculatus*) and alfalfa (*Medicago sativa*) species from the legume family (*Fabaceae*) were germinated in laboratory conditions at 2, 4, 6, 8 and 10 °C with 4 replications. The seeds were left to germinate for 20 days, and those that germinated were identified at 24-hour intervals. At the end of the study, germination rate, germination potential and mean germination time were determined. The data obtained were evaluated separately for each species. Before analysis of variance, Shapiro-Wilk and Levene tests were applied to the data, and then, when necessary, transformations were made and analysis of variance was applied in a randomized plot design or t test used. The differences between the means were determined by the Tukey multiple comparison test. As a result of the analysis of variance, it was determined that low temperature values had a statistically significant effect on the germination rate, germination potential and mean germination time of seeds in each species. While germination did not occur at 2 °C in birdsfoot trefoil seeds, the others species of seeds germinated at 2 °C in the study. The increase in temperature germination of seed increased. White clover germinated 100% at 10 °C, and red clover at 8 °C. At the same time, as the temperature increased, the mean germination time and germination initiation also shortened.
Keywords: Seed, Germination, Temperature

GİRİŞ
Tohumun çimlenmesinde bitkisel ve çevresel faktörler olmak üzere bir çok faktör etkilidir. Bu faktörlerden birisi de sıcaklıktır. Sıcaklık, bitki tohumlarındaki enzim aktivitesini uyararak tohum kabuğunun yırtılmasına yol açtığı ve su geçirgenliğini arttırdığı için tohum uyku halinin kırılması ve tohum çimlenmesinin tetiklenmesi için önemlidir (Liu ve ark., 2022). Sıcaklık ne kadar yüksek olursa, su emilimi o kadar hızlı olur.

Soğuk su sadece süreci yavaşlatmakla kalmaz, aynı zamanda bu tür termal koşullara uyum sağlayamayan hücre zarları için de tehdit oluşturur (Szczerba ve ark., 2021). Tohum çimlenmesinin sıcaklığa tepkisi genellikle parabolik bir ilişki ile karakterize edilir. Tohum çimlenmesi için optimal bir sıcaklık vardır ve optimumun üzerindeki veya altındaki sıcaklıklar tohum çimlenmesini engelleyebilir (Liu ve ark., 2022). Serin mevsim türlerinde çimlenme için optimum sıcaklık 10 ila 20 °C arasında değişmektedir (Baskin ve Baskin, 2001). Bu sıcaklık aralığında çimlenme oranı en hızlıdır ancak serin mevsim türlerinin çoğunda çimlenme daha düşük sıcaklıkta başlayabilir (Gullap ve ark., 2018).

Küresel iklim değişikliği sonucunda sadece sıcaklık artışı yaşanmamakta aynı zamanda sıcaklık düzenlerinde değişiklikler de yaşanmaktadır (Anonim, 2023). Sıcaklık artışıyla toprak yüzey sıcaklığında kademeli bir artış, kış mevsiminde kısalmalar, ilkbahar başında karların erken erimesi (Liu ve ark., 2022), yağış rejiminde düzensizlikler yaşanmaktadır. Tüm bu değişimler bitkisel üretimde ekim zamanını değiştirmektedir. Kışlık ekimlerde ekimin gecikmesi veya ekimden sonra yaşanan ani sıcaklık değişimleri, soğuk bölgelerde erken ilkbaharda yaşanan soğuklar tohumların düşük çimlenme sıcaklıklarına maruz kalmasına sebep olacaktır.

Gerek doğal gerekse yapay çayır meralarda bir çok bitki türü bir arada yetişmektedir. Tohumun çimlenmesi, bitkilerde büyümenin ilk aşaması olmakla birlikte hem bitki bireylerinin gelişimi ve çoğalmasını hem de bitki topluluğunun (vejetasyonun) yapısını ve kompozisyonunu etkiler (Liu ve ark., 2022). Böylece elde edilen verim ve ot kalitesi değişir. Ak üçgül, çayır üçgülü, gazal boynuzu ve yaygın yonca çayır meralarda bir arada bulunabilen çok yıllık baklagil yem bitkileridir.

Bu çalışma, ak üçgül *(Trifolium repens)*, çayır üçgülü *(Trifolium pratense)*, gazal boynuzu (*Lotus corniculatus)* ve yaygın yonca (*Medicago sativa)* türlerinin düşük sıcaklıklarda çimlenme özelliklerinin belirlenmesi amacıyla yürütülmüştür.

MATERYAL VE METOT

Ak üçgül, çayır üçgülü, gazal boynuzu ve yaygın yonca türlerine ait tohumlar, laboratuvar şartlarında 2, 4, 6, 8 ve 10 °C sıcaklıkta, karanlık ortamda çimlendirilmiştir. Tohumlar petride kağıt arasında, her petride 25 tohum olacak şekilde 4 tekrarlamalı olarak çimlendirilmiştir. Çimlenme analizi 20 gün süreyle devam etmiş ve her gün aynı saatte çimlenen tohum sayısı belirlenmiştir. Çalışma sonunda çimlenme oranı, çimlenme potansiyeli (Wang ve ark., 2016) ve ortalama çimlenme süresi (Matthews ve Khajeh-Hosseini, 2007) belirlenmiştir. Her bir tür için elde edilen veriler ayrı ayrı istatistik analize tabi tutulmuştur. İstatistik analiz öncesinde denemeden elde edilen verilerin normal dağılımları Shapiro-Wilk testi ile varyansların homojenliği ise Levene testi ile kontrol edilmiştir. Normal dağılış göstermeyen ve homojen olmayan çimlenme oranı değerlerine arcsin transformasyonu, ortalama çimlenme süresi değerlerine ise $\sqrt[2]{X+1}$ transformasyonu uygulanmıştır. Elde edilen verilere tesadüf parselleri deneme desenine göre varyans analizi yapılmış ve ortalamalar Tukey testi ile karşılaştırılmıştır. Ancak ak üçgülde çimlenme potansiyeli değerleri sadece 8 ve 10 °C de hesaplanabildiğinden, ve varyanslar homojen olduğundan bağımsız örneklem t testi yapılmıştır. Hesaplamalarda ve yorumlamalarda α=%5 dikkate alınmıştır. Tüm hesaplamalar SPSS 20 istatistik paket programı ile yapılmış, grafikler Excell ile çizilmiştir.

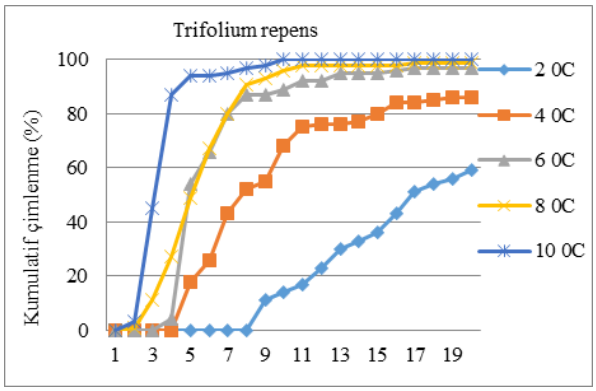
BULGULAR

Yapılan varyans analizi sonucunda, araştırmada incelenen bütün türlerde çimlenme oranı bakımından sıcaklıklar arasında istatistiki olarak önemli farklılık olduğu belirlenmiştir. Araştırmada ak üçgül, çayır üçgülü, yaygın yonca tohumlarında 2 °C'de çimlenme gerçekleşirken, gazal boynuzu tohumlarında ise çimlenme olmamıştır. Bununla birlikte 2 °C'de en yüksek çimlenme oranı % 81 ile çayır üçgülünde belirlenirken, bu değer ak üçgülde % 59, yaygın yoncada ise % 74 olmuştur. Çimlenme ortamında sıcaklık arttıkça ak üçgül ve çayır üçgülünde çimlenme oranları da artmıştır. Ak üçgülde 10 °C'de % 100 çimlenme oranına ulaşılırken, çayır üçgülünde 8 ve 10 °C'lerde çimlenme oranı % 100 olmuştur. Yaygın yonca ve gazal boynuzu türlerinde çimlenme ortamının sıcaklığı 2 °C'den 8 °C'ye çıktığında çimlenme oranları da artmış, ancak sıcaklığın 10 °C'ye yükselmesiyle çimlenme oranlarında önemsiz düzeyde bir azalış meydana gelmiştir. Gazal boynuzunda her ne kadar çimlenme ortamının sıcaklığının artması çimlenme oranını artırıcı etki yapsa da belirlenen çimlenme oranı oldukça düşük olmuştur (maksimum çimlenme oranı % 58 olmuştur).

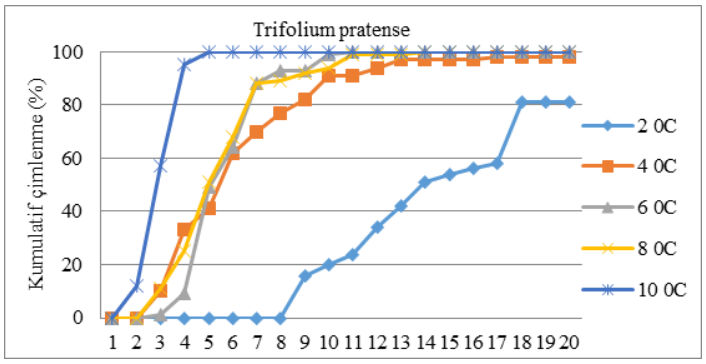
Çizelge 1. Bazı baklagil türlerinin düşük sıcaklık değerlerinde çimlenme oranları (%)[x]

Sıcaklık (°C)	Ak üçgül	Çayır üçgülü	Gazal boynuzu	Yaygın yonca
2	59,0±5,3c	81,0±10,0b	0,0±0,0d	74,0±5,0b
4	86,0±2,0b	98,0±1,2a	19,0±3,4c	76,0±1,6ab
6	97,0±1,0a	99,9±0,0a	39,0±1,9b	77,0±3,8ab
8	99,0±1,0a	100,0±0,0a	58,0±3,5a	90,0±2,6a
10	100,0±0,0a	100,0±0,0a	55,0±1,9a	87,0±4,7ab
P değeri	0,000*** (F=46,718)	0,001*** (F= 8,650)	0,000*** (F=165,233)	0,029 (F=3,624)

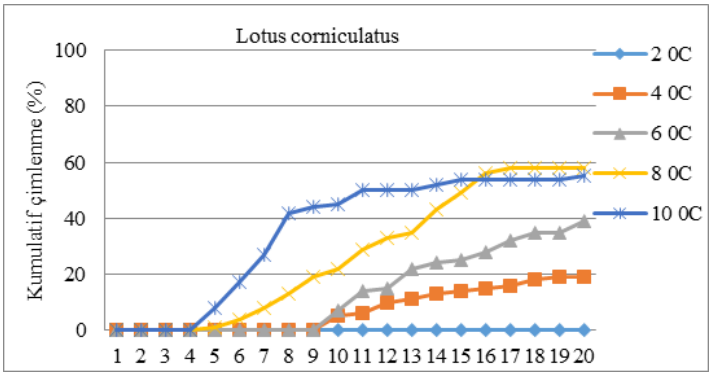
Veriler ortalama±standart hata şeklinde sunulmuştur. ***istatistik olarak önemlidir (p <0.001), ortak küçük harfi olmayan sıcaklıklar arasındaki fark istatistiksel olarak önemlidir (p<0.05).
Kümülatif çimlenme oranları incelendiğinde, çimlenme başlangıcının her bir türde sıcaklığa bağlı olarak değiştiği görülmektedir. Çimlenme ortamının sıcaklığı 2 °C olduğunda, çimlenme yaygın yoncada 7. günde, ak üçgül ve çayır üçgülünde ise 9. günde başlarken, gazal boynuzunda ise araştırma süresince (20 gün boyunca) çimlenme başlamamıştır. Ortam sıcaklığı 4 °C'ye yükseldiğinde ise gazal boynuzu tohumları 10. günde çimlenmeye başlamışlar, bu süre yaygın yonca ve çayır üçgülünde 3. güne ak üçgülde 5. güne gerilemiştir. Araştırmada incelenen en yüksek sıcaklık olan 10 °C'de ise 4 baklagil türünde de çimlenme 2. günde başlamıştır (Grafik 1, 2, 3 ve 4). Bu durum bize sıcaklık artışının çimlenme başlangıcı için gerekli süreyi kısalttığını göstermektedir. Yine kümülatif çimlenme oranları incelendiğinde, çimlenme ortamında sıcaklığın artması ile birlikte araştırmada incelenen her bir tür için belirlenen maksimum çimlenme oranına ulaşılan sürenin de kısaldığı anlaşılmaktadır. Örneği çayır üçgülünde ortam sıcaklığı 6 °C olduğunda % 100 çimlenme 11. günde gerçekleşirken, sıcaklık 10 °C'ye yükseldiğinde bu orana 5. günde ulaşılmıştır (Grafik 2).



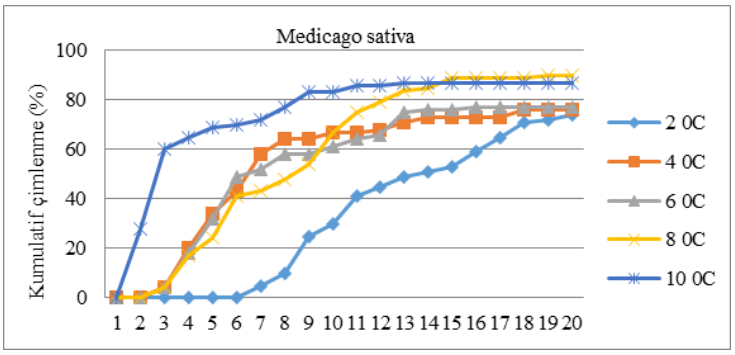
Grafik 1. Farklı sıcaklıklarda ak üçgül tohumlarının kumulatif çimlenme oranı (%)



Grafik 2. Farklı sıcaklıklarda çayır üçgülü tohumlarının kumulatif çimlenme oranı (%)



Grafik 3. Farklı sıcaklıklarda ak üçgül tohumlarının kumulatif çimlenme oranı (%)



Grafik 4. Farklı sıcaklıklarda yaygın yonca tohumlarının kumulatif çimlenme oranı (%)

Çizelge 2'de görüldüğü üzere, yonca ve çayır üçgülü tohumlarının 2 °C'de, ak üçgül tohumlarının 2, 4 ve 6 °C'de, gazal boynuzu tohumlarının ise incelenen bütün sıcaklık değerlerinde, çimlenme potansiyeli % 0 olduğu belirlenmiştir.

Çizelge 2. Bazı baklagil türlerinin düşük sıcaklık değerlerinde çimlenme potansiyeli (%)[x]

Sıcaklık (°C)	Ak üçgül	Çayır üçgülü	Gazal boynuzu	Yaygın yonca
2	0,0±0,0	0,0±0,0c	0,0±0,0	0,0±0,0c
4	0,0±0,0	10,0±2,6b	0,0±0,0	4,0±2,8b
6	0,0±0,0	1,0±1,0c	0,0±0,0	4,0±2,8b
8	11,0±1,9b	11,0±1,9b	0,0±0,0	4,0±1,6b
10	45,0±6,8a	57,0±1,9a	0,0±0,0	60,0±1,6a
P değeri	0,003*** (t=4,81)	0,000*** (F=99,578)		0,000*** (F=39,400)

[x]Veriler ortalama±standart hata şeklinde sunulmuştur. ***istatistik olarak önemlidir ($p < 0.001$), ortak küçük harfi olmayan sıcaklıklar arasındaki fark istatistiksel olarak önemlidir ($p < 0.05$).

Yonca ve çayır üçgülünde, çimlenme potansiyeli bakımından çimlenme sıcaklıkları arasında istatistiki olarak önemli ($p < 0.001$) farklılık varken, ak üçgülde çimlenme sıcaklığı 8 °C'den 10 °C'ye çıktığında çimlenme potansiyeli istatistiki olarak önemli derecede ($p < 0.001$) artmıştır. Çimlenme ortamının sıcaklığı 10 °C'ye yükseldiğinde yonca, çayır üçgülü ve ak üçgül tohumlarının çimlenme potansiyeli en yüksek değere ulaşmıştır. Bu durum, sıcaklığın tohumların çimlenme hızını artırdığını göstermektedir.

Ortalama çimlenme süresi değerlerine yapılan varyans analizi sonucunda, ak üçgül, çayır üçgülü ve yaygın yonca türlerinde çimlenme sıcaklığının ortalama çimlenme süresi üzerinde istatistiki olarak önemli ($p < 0.001$) etkisi olduğu belirlenmiştir. Çimlenme ortamının sıcaklığı arttıkça söz konusu türlerde ortalama çimlenme süresi kısalmıştır. Bu nedenle her 3 türde de en uzun ortalama çimlenme süresi 2 °C'de, en kısa süre ise 10 °C'de hesaplanmıştır. Bununla birlikte her 3 türde ortalama çimlenme süresindeki ilk önemli azalma çimlenme sıcaklığı 2 °C'den 4 °C'ye çıktığında gerçekleşmiştir. Gazal boynuzu tohumlarında 2 °C'de çimlenme gerçekleşmediğinden ortalama çimlenme süresi de hesaplanamamıştır.

Bu nedenle varyans analizi diğer sıcaklık değerlerinde elde edilen verilere uygulanmış ve varyans analizi sonucunda ortalama çimlenme süresi bakımından sıcaklıklar arasındaki farklılık önemsiz bulunmuştur.

Çizelge 3. Bazı baklagil tohumlarının düşük sıcaklık değerlerinde ortalama çimlenme süresi (gün)[x]

Sıcaklık (°C)	Ak üçgül	Çayır üçgülü	Gazal boynuzu	Yaygın yonca
2	15,85±1,23a	19,1±0,8a	--	14,0±1,2a
4	8,74±0,41b	6,4±0,3b	21,95±8,39	7,1±0,4bc
6	6,36±0,37c	6,0±0,2b	17,34±1,500	7,0±0,5bc
8	5,86±0,11c	5,9±0,3b	11,65±0,51	8,2±0,9b
10	3,87±0,19d	3,4±0,0c	8,27±0,35	4,0±0,2c
P değeri	0,000***(F=80,066	0,000*** (F=223,785)	0,069 (F= 3,060)	0,000*** (F=25,842)

[x]Veriler ortalama±standart hata şeklinde sunulmuştur. ***istatistik olarak önemlidir ($p < 0.001$), ortak küçük harfi olmayan sıcaklıklar arasındaki fark istatistiksel olarak önemlidir ($p < 0.05$).

TARTIŞMA

İstenilen bitki populasyonunun başarılı bir şekilde elde edilmesinde ilk koşul yeterli sayıda tohumun çimlenmesi ve fide gelişiminin sağlanmasıdır. Ancak tohumların sıcaklığa cevabı komplekstir (Lei ve ark., 2013). Çimlenmede sıcaklık, minimum, optimum ve maksimum sıcaklık değeri olmak üzere 3 farklı etkiye sahip olmakla birlikte, sıcaklık tohumun dormansiden çıkmasına (Liu ve ark., 2022) veya dormansiye girmesine de etki etmektedir. Çalışmamızda gazal boynuzu tohumları 2 °C'de hiç çimlenmemiştir. Bilindiği üzere minimum çimlenme sıcaklığı altındaki sıcaklıklarda tohumlar çimlenmemektedir. Her ne kadar gazal boynuzu için % 50 çimlenme sıcaklığı 4.7 °C (Hur ve Nelson, 1985) olarak belirlense de çalışmamızda 4 ve 6 °C'de çimlenme oranı % 50'nin altında kalmıştır. Bu durum genotipik farklılıktan ve tohumların üretildiği ekolojilerin farklılığından kaynaklanmış olabilir. Diğer 3 türde ise 2 °C'de tohumlarda çimlenme gerçekleşmiş ve çimlenme oranı % 50'nin üzerinde olmuştur. Yonca, çayır üçgülü ve ak üçgül için % 50 çimlenme sıcaklığının çeşitlere göre değiştiği ve sırasıyla 0.7-1.2 °C, 0.0-1.5 °C ve 0.0-1.3 °C olarak bildirilmiştir (Moot ve ark., 2000). Başka bir çalışmada ise yaygın yoncanda genotiplere göre % 50 çimlenme sıcaklığının (- 0.55) ile 0.49 °C arasında değiştiği belirlenmiştir (Jungers ve ark., 2016). Elde edilen çimlenme oranları belirtilen sıcaklık değerleri ile uyumludur. Düşük sıcaklık değerleri çalışmada incelenen bütün türlerde çimlenme başlangıcını geciktirmiş, ortalama çimlenme süresini ise uzatmıştır. Her bir bitki türü için çimlenmede gerekli olan optimum sıcaklığın altındaki düşük sıcaklık, tohumlarda enzim aktivitesini ve su alımını azaltır (Liu ve ark., 2022), tohumda bulunan depo maddelerinin taşınmasını yavaşlatır, çimlenme ve fide gelişimi için gerekli metabolik olayları sınırlandırır (Haj Sghaier ve ark., 2022). Bununla birlikte soğuk, hücrelerin metabolik dengesini bozar, hücrelerde fazla miktarda reaktif oksijen türleri birikir (Fu ve ark., 2017). Yapılan çalışmalarda düşük sıcaklığın çimlenme oranını azalttığı (Fu ve ark., 2017; Gullap ve ark., 2018; Liu ve ark., 2022), çimlenme başlangıcını geciktirdiği (Gullap ve ark., 2018; Liu ve ark., 2022), çimlenme süresini ise uzattığı (Fu ve ark., 2017; Khaeim ve ark., 2022) bildirilmiştir.

SONUÇ

Serin mevsim baklagil yem bitkilerinde düşük sıcaklıklarda çimlenme seyrinin bilinmesi kışlık ekimlerin gecikmesinde veya ani soğukların yaşanması durumunda kritik öneme sahiptir. Her ne kadar özellikle kışlık geç ekimlerde çimlenmenin gerçekleşmesi olumlu bir durum gibi görünse de bitkilerin hayatta kalması fidelerin soğuğa dayanımına bağlıdır. Bu noktadan bakıldığında yapay alanlarda botanik kompozisyonun şekillenmesinde çimlenme döneminde yaşanan sıcaklıkların önemli etkisi olduğu düşünülmektedir. Ayrıca söz konusu düşük sıcaklıklarda fide gelişimi ve soğuğa dayanımının belirlendiği çalışmaların yapılması konunun aydınlatılmasında faydalı olacaktır.

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GEÇİT İKLİMDE MERA ISLAHI: AKBUDAK KÖYÜ ÖRNEĞİ

PASTURE IMPROVEMENT IN TRANSITIONAL CLIMATE CONDITIONS: THE AKBUDAK VILLAGE EXAMPLE

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ÖZET
Bu çalışma T.C. Tarım ve Orman Bakanlığı tarafından desteklenen mera ıslah projesi olarak, Giresun-Şebinkarahisar Akbudak köyünde yürütülmüştür. Mera alanı yaklaşık 328 da olup mevcut haliyle meranın tamamını hayvanlar otlayamamaktadır. Mera alanının eğimi %0-2, 900-910 m rakımda, 500-650 mm yağış kuşağında, normal meradır. Mera içerisinde bitki örtüsü bakımından farklılık gösteren 4 mera kesimi bulunmaktadır. En büyük mera kesimi 280 da olup, 54 da alan taşlık, 138 da çalılık geriye kalan yaklaşık 89 da ise otsu türlerle kaplıdır. Dolayısıyla bu mera kesiminde hayvanlar 89 da alanda otlayabilmektedir. Geriye kalan 3 mera kesiminde ise çalılık alan yok denecek kadar azdır. Bununla birlikte bitki örtüsünün büyük ölçüde zarar gördüğü alanlar mevcuttur. Merada azalıcı+çoğalıcı bitkilerin oranı % 40 olup, mera durumu orta sınıftadır. Merada azalıcı türlerden *Trifolium repens, Trifolium pratense, Lotus corniculatus, Lotus gebelia, Medicago sativa, Trifolium fragiferum, Dactylis glomerata, Lolium perenne, Sanguisorba armena* türleri bulunmaktadır. Merada ıslah işlemi olarak yabancı ot mücadelesi, havalandırma, yapay mera tesisi, sulama, gübreleme, temizlik biçimi, taş toplama, tesviye işlemleri yapılmıştır. Söz konusu ıslah işlemleri, mera kesimlerinin durumlarına uygun olarak yalın veya birkaç yöntem birlikte uygulanmıştır. Mera ıslahı öncesinde faydalanılabilir yeşil yem miktarı 45 kg/da olarak hesaplanmıştır. Yapılan mera ıslahı sonucunda, hayvanların otlayacağı mera alanı yaklaşık 195 da artmıştır. Yanısıra faydalanılabilir yem miktarı 2 katına çıkmıştır.
Anahtar Kelimeler: Mera, Islah, Ot verimi

ABSTRACT
This study was conducted in Akbudak village, Şebinkarahisar, Giresun, as a pasture improvement project supported by the Ministry of Agriculture and Forestry of the Republic of Turkey. The pasture area is approximately 328 decares, and in its current state, animals cannot graze the entire area. The pasture area has a slope of 0-2%, is located at an altitude of 900-910 m, and receives 500-650 mm of rainfall; it is considered a normal pasture. Within the pasture, there are four sections with differing vegetation. The largest section is 280 decares, of which 54 decares are rocky, 138 decares are shrubland, and the remaining approximately 89 decares are covered with herbaceous plants. Therefore, animals can only graze in 89 decares of this section. In the remaining three sections, shrubland is almost nonexistent. However, there are areas where the vegetation has been significantly damaged. The ratio of decreasing and increasing plants in the pasture is 40%, and the pasture condition is considered medium. The declining species found in the pasture include *Trifolium repens*, *Trifolium pratense*, *Lotus corniculatus*, *Lotus gebelia*, *Medicago sativa*, *Trifolium fragiferum*, *Dactylis glomerata*, *Lolium perenne*, and *Sanguisorba armena*. Pasture improvement methods included weed control, aeration, artificial pasture, irrigation, fertilization, mowing at the end of the grazing season, stone removal, and leveling. These improvement methods were applied individually or in combination, depending on the condition of the pasture sections. Prior to pasture improvement, the available green fodder was estimated at 45 kg/da. As a result of the pasture improvement, the grazing area for animals increased by approximately 195 da, and the available fodder doubled.
Keywords: Pasture, Improvement, forage yield

GİRİŞ

Türkiye'de 1998 yılında çıkarılan 4342 sayılı mera kanunu kapsamında bir yandan meralarda tespit ve tahsis işlemleri yapılırken, bir yandan da Bakanlık tarafından yürütülen mera ıslah çalışmaları yapılmaktadır. 1998-2002 yılları arasında 83.527 da alanda ıslah çalışması yapılmışken, 2003-2026 yılları arasında ise 26.557.196 da mera, toplam 3.332 adet proje ile ıslah edilmiştir (Anonim, 2026a). Islah projeleri yapılmaya devam edilmektedir.

Giresun ilinde toplam 103.264 ha mera alanı bulunmakta ve 45.769 ha'ı geçit iklimin yaşandığı iç bölgede yer almaktadır (Altındal ve Önal Aşcı, 2024). Giresun ili meralarında yaklaşık 20 yıldır mera ıslahı yapılmakta olup bu kapsamda bir çok merada ıslah projesi yürütülmüştür. Aynı zamanda hemen hemen her yıl en az 1 adet proje ile mera ıslahına devam edilmektedir.

Giresun ili kıyıya paralel uzanan Giresun dağlarının etkisiyle eğimli, engebeli topografik yapıya sahip ve iklimsel olarak farklı bölgelere ayrılmaktadır. Aynı zamanda meraların çoğu yaylalarda bulunduğundan kullanım durumu ve iklim kaynaklı bir çok problem yaşanmaktadır (Altındal ve Önal Aşcı, 2024).

Son yıllarda yaşanan iklim değişikliği ülkemizin tamamında etkilerini göstermekle birlikte özellikle Karadeniz Bölgesi'nde yaz mevsiminde aşırı yağışlara neden olmakta, aşırı yağışlar ise heyelan, sel ve su baskınları ile can ve mal kayıplarına neden olmaktadır. Örneğin temmuz sonu- Ağustos ortası 2026 dönemde Giresun'un iki farklı ilçesinde sel olmuş (Anonim, 2026b) ve 5 can kaybı yaşanmıştır (Daban, 2026).

Meraların ıslahı ile ot verimi ve kalitesini artırmak, hayvanların meradan daha iyi faydalanmasını sağlamak sadece hayvancılığı daha kârlı hâle getirmekle kalmamakta aynı zamanda da toprağın ve suyun yerinde tutulmasını sağlamaktadır. Böylece sel ve su baskınları riskini azaltmak mümkün olacaktır.

Bu çalışma Giresun ili Şebinkarahisar ilçesi Akbudak köyü merasınının ıslahı amacıyla yürütülmüştür.

MATERYAL VE METOT

Mera ıslah projesi Tarım orman bakanlığı tarafından Giresun ili Şebinkarahisar ilçesi Akbudak köyü merasında, 328 da alanda yürütülmüştür. Mera alanı % 0-2 eğimli, 500-650 mm yağış kuşağında, 900-910 rakımda yer almaktadır. Mera alanı Karadeniz Bölgesi geçit iklimine sahiptir. Kışları kar yağışlı soğuk, yazları ise sıcak ve kurak geçmektedir.

Merada yapılan ayrıntılı inceleme sonucunda, ıslah işlemleri için farklı sorunların tespit edildiği 4 mera kesimi belirlenmiştir:

1. Dere kenarındaki ağaç ve çalıların oluşturduğu odunsu bitki örtüsü bulunan alan. Bu alanda aynı zamanda daha önce dere taşkınına bağlı taşlılık sorunu da bulunmaktadır.
2. Juncus sp. yoğun olduğu alan. Bu alana çevresindeki tarlaların kontrolsüz sulanması ile aşırı su akışı olmuştur.
3. Belediyenin ve Orman işletmenin bitki örtüsünü yok ettiği alan (toprak dökmek ve yol açmak) ile seyrek odunsu türlerin bulunduğu alan
4. Mevcut otsu vejetasyonun iyileştirileceği alan.



Şekil 1. Meranın genel görünümü

Mera genelinde vegetasyonda bulunan türler, azalıcı, çoğalıcı ve istilacı türler olarak sınıflandırılmıştır. İnceleme sonucunda azalıcı türlerden *Trifolium repens, Trifolium pratense, Lotus corniculatus, Lotus gebelia, Medicago sativa, Trifolium fragiferum, Dactylis glomerata, Lolium perenne, Sanguisorba armena,* çoğalıcı türlerden *Medicago lupilina, Cynodon dactylon, Poa sp., istilacı türlerden ise Crataegus orientalis, Rubus sp., Rosa sp., Salix alba, Silybum marianum L., Centaurea hypoleuca, Centaurea drabifolia, Centaurea armena, Carthamus sp., Chondrilla juncea, Taraxacum officinalis, Anchusa sp., Echium sp.,Euphorbia sp., Ononis spinosa, Geraniumsp., Polygonum aviculare, Polygonum bellardii, Rumex sp., Anagallis sp., Juncus sp., Tamarix sp.* türlerine rastlanmıştır.
Yukarıda açıklanan 4 mera kesiminde şu mera ıslah işlemleri uygulanmıştır:

1. Mera kesiminde: odunsu türlerin sökümü, taş toplama, tesviye, yeniden ekim, gübreleme
2. Mera kesiminde: havalandırma, juncus ile lokal mücadele (herbisit uygulaması), üstten tohumlama, gübreleme, kontrollü sulama
3. Mera kesiminde: Bitki örtüsünün yok edildiği alanda, tesviye işlemi, ekim, gübreleme; odunsu türlerin seyrek olduğu alanda lokal olarak herbisitle mücadele, gübreleme
4. Mera kesiminde: Gübreleme, sulama

Uygulamaları yapılmıştır.
Otlatma mevsimi sonunda bütün merada otlanmadan kalan bitkilere temizleme biçimi yapılmıştır.
Merada yeniden ekimde *Trifolium repens+Festua arundinaceae+Lolium perenne* ve *Dactylis glomerata* türlerinden oluşan karışım (Her bir tür % 25 oranında yer almıştır) ekilmiştir. Yeniden ekilen alanlarda ekimle birlikte 5 kg N ve 5 kg P_2O_5/da olacak şekilde gübreleme yapılmıştır.
Ekim yapılmayan alanların gübrelemesinde ise 4 kg N ve 4 kg P_2O_5/da olacak şekilde ilkbaharda gübreleme yapılmıştır.
Uygulamadan elde edilen sonuçlar tekrarlamalı veri niteliğinde olmadığından verilere herhangi bir istatistik analiz yapılmamıştır. Sonuçlar görseller ve sayılarla sunulmuştur.

BULGULAR ve TARTIŞMA

Proje daha öncede ifade edildiği üzere 328 da alanda uygulanmıştır. Ancak projeden önce merada hayvanların yararlanabildiği alan 135 da iken, proje ile 195 da alan daha hayvanların otlayabildiği mera alanına dönüştürülmüştür. Böylece proje sonunda hayvanların otlayacağı alanda 2 katından daha fazla artış sağlanmıştır.



Şekil 2. Merada odunsu türlerin yok edilerek yeniden ekim yapılan alan

Yanısıra gübreleme, üstten tohumlama, havalandırma, taş toplama, lokal herbisit uygulamaları sonucunda meradan elde edilen ot verimi artmıştır. Meranın ıslah öncesinde yağış kuşağı ve mera durumu dikkate alındığında faydalanılabilir kuru ot verimi 45 kg/da olarak hesaplanmıştır. Hâlbuki ıslah sonrasında faydalanılabilir kuru ot verimi 90 kg/da olarak hesaplanmıştır. Meranın ıslah öncesinde orta olan durumu, ıslah sonrasında iyi olmuştur. Bu durumda meranın veriminin de 2 katına çıkmıştır.



Şekil 3. Yeniden ekim yapılan alandan görünüm



Şekil 4. Islah sonrası doğal bitki örtüsü bulunan mera alanından görünüm

Gerek alan artışı gerekse verim artışı ile birlikte başlangıçta 6075 kg kuru ot (135 da x 45 kg) olan faydalanılabilir ot miktarı, proje sonunda 29700 kg kuru ota (330 da x 90 kg) çıkmıştır. Verimliliğini ve kalitesini kaybetmiş mera alanları bitki örtüsü, iklim ve toprak özellikleri dikkate alınarak uygun ıslah yöntemi ve/veya yöntemleri ile ıslah edildiğinde meranın ot verimi ve kalitesinin artırıldığı bir çok çalışma sonucunda bildirilmiştir (Ayan ve Acar, 2008; Aydın ve Uzun, 2000; Acar ve ark., 2023). Bitki örtüsünün tamamen yok olduğu veya iyi cins yem bitkilerinin çok çok azaldığı alanlarda kısa sürede yüksek verimli mera oluşturmada en etkili ıslah yöntemi yapay mera tesisidir (Altın ve ark., 2005; Önal Aşcı ve Şimşek Soysal, 2023). Bu çalışmada da odunsu türlerin yoğun olduğu alan ile yanlış kullanımla bitki örtüsü tamamen yok olan alanda yapay mera kurulmuştur.
Ülkemizde meralar çok uzun yıllardır hiç bir yönetim ilkesine uyulmadan kullanıldığı için verimliliklerini ve iyi cins yem bitkileri maalesef önemli derecede kaybetmişlerdir. Bununla birlikte meralarda zaman zaman mera dışı kullanımlar da olmaktadır (Ayan ve ark., 2007). Bu merada Belediye ve Orman İşletmenin mera üzerindeki bitki örtüsünü yok eden kullanımları sonucunda, meranın bir bölümü tamamen hayvanlar için kullanılamaz duruma gelmiştir.

SONUÇ

Yapılan çalışmada iyi cins yem bitkileri vejetasyona ilave edilmiş, gübreleme ile bitkilerin verimliliği artırılmıştır. Ayrıca hayvanların değerlendiremediği alanlara kaliteli yem bitkileri ekilmiş ve gübrelenerek yüksek verimli mera oluşturulmuştur. Böylece ıslah çalışması sonucunda tahsis edilen meranın tamamı hayvanların yararlandığı alanlara dönüşmüş, yüksek verimli ve kaliteli ot elde edilmiştir.

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UÇAKLARDA KULLANILAN ELYAF TAKVİYELİ KARBON/EPOKSİ KOMPOZİT VE 2024-T3 AL ALAŞIMLARINDA YORULMA HASARI OLUŞUMU VE İLERLEMESİ

FATIGUE DAMAGE INITIATION AND PROPAGATION IN FIBER REINFORCED CARBON/EPOXY COMPOSITES AND 2024-T3 AL ALLOYS USED IN AIRCRAFT

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ÖZET
Hava aracı yapılarında gövde, kanat ve taşıyıcı bileşenlerin tasarımı, hafiflik ve yüksek hasar toleransı gereksinimlerini aynı anda karşılamayı zorunlu kılmaktadır. Bu çalışmada, uçaklarda yaygın olarak kullanılan geleneksel 2024-T3 alüminyum alaşımı ile yapısal ağırlığı azaltma potansiyeli sunan sürekli elyaf takviyeli karbon/epoksi kompozitlerin (CFRP) yorulma davranışı, hasar oluşumu ve ilerleme mekanizmaları açısından karşılaştırmalı olarak incelenmiştir. Her iki malzeme grubunun yorulma testleri yapılmış ve yorulma ömürleri boyunca oluşan hasar mekanizmaları belirlenmiştir. Al alaşım numunede yorulma çatlağı, numunede oluşturulan çentikten başlamakta ve makro seviyede tek bir çatlak şeklinde yükleme eksenine 90 derece ilerlemektedir. CFRP numunelerde ise hasar birçok noktadan başlamakta ve elyaf oryantasyonlarına bağlı olarak makro seviyede farklı kırılma karakteristikleri göstermektedir. Yorulma testlerine tabi tutulmuş hasarlı parçalar mikro seviyede incelendiğinde, Al alaşımlarında yorulma çizgileri en belirgin özellik olarak görülmektedir. Bu çizgiler; hasar modunu, çatlak başlangıç ve ilerleme hızı özelliklerini çok iyi karakterize etmektedir. CFRP numunelerde ise mikro seviyede, yorulma ömrünün başlangıcında reçine zengin bölgelerde ve elyaf demetlerinde enine çatlaklar oluşmaktadır. Bu aşamada malzeme rijitliğinde yaklaşık %8 azalma olmaktadır. Daha sonra elyaf-matris arası çatlakların ilerlemesi, tabaka ayrılmaları, gevrek matris çatlaklarının ilerlemesi ve elyaf kırılmaları şeklinde yorulma hasarları ilerlemektedir. Kırık yüzey özellikleri elyaflardan çok matris malzemesinde oluşan izler ile karakterize edilmektedir. CFRP malzemelerin yorulma ömürlerinin son safhasında elyaf oryantasyonuna bağlı olarak tabaka ayrılmaları aşırı derecede ilerlemekte ve elyaf kırılmaları neticesinde parçalar birkaç noktadan kırılmaktadır. Çalışmada elde edilen makroskobik ve mikroskobik karakteristikler derlenerek, araştırmacıların ve hasar analistlerinin Al alaşımları ile CFRP kompozitlerdeki temel hasar nedenlerini saptayabilmesi için makro ve mikro kırılma özelliklerini içeren bir hasar mekanizması tablosu oluşturulmuştur. Bu tablo, uçak kaza/kırım incelemelerine faydalı veriler sunmasının yanı sıra; uçak yapısal tasarım süreçleri, hasar toleransı gerekliliği ve malzemelerin sünek-gevrek karakterine bağlı malzemeye özgü hasar ilerleme mekanizmalarının anlaşılması için önemli veriler içermektedir.
Anahtar Kelimeler: 2024-T3 Alüminyum Alaşımı, Sürekli Elyaflı Karbon/Epoksi Kompozit, Yorulma Hasar Mekanizmaları

ABSTRACT
The design of aircraft fuselage, wing, and load-bearing components necessitates satisfying lightweight and high damage tolerance requirements simultaneously. This study comparatively investigates the fatigue behavior, damage initiation, and growth mechanisms of 2024-T3 aluminum alloy and continuous fiber-reinforced carbon/epoxy composites (CFRP). Fatigue tests were performed on both materials to determine the damage mechanisms occurring throughout their fatigue lives. In the aluminum alloy, a single macro-level fatigue crack initiates from a notch and propagates 90° to the loading axis. Conversely, CFRP specimens exhibit multi-point damage initiation and varying macro-level fracture characteristics depending on fiber orientations. Microscopic examination reveals fatigue striations as the most prominent feature in aluminum alloys, characterizing the damage mode, crack initiation, and growth rate very well. In CFRP, transverse cracks form in resin-rich areas and transverse fiber bundles early in the fatigue life. This stage causes an approximate 8% decrease in material rigidity. Subsequently, fatigue damage propagates via fiber-matrix interface crack propagation, delaminations, brittle matrix cracking, and fiber fractures. Fracture surfaces are characterized more by matrix traces than fibers.

In the final stage of the fatigue life of CFRP materials, delamination progresses excessively depending on fiber orientation, and the parts fracture at several points as a result of fiber fractures. By compiling the macroscopic and microscopic characteristics obtained in the study, a damage mechanism table containing macro and micro fracture properties was created to enable researchers and failure analysts to determine the causes of damage in Al alloys and CFRP composites. This table provides useful data for aircraft accident/crash investigations conducted by failure analysts, as well as containing important data for understanding aircraft structural design processes, material-specific damage propagation mechanisms and damage tolerance requirements depending on the ductile-brittle character of the materials.

Keywords: 2024-T3 Aluminum Alloy, Continuous Fiber Carbon/Epoxy Composite, Fatigue Damage Mechanisms.

MEYVE VE SEBZE ATIĞI KOMPOSTUNUN FESLEĞEN (OCIMUM BASILICUM L.) YETİŞTİRİCİLİĞİNDE KULLANIMI VE BİTKİ GELİŞİMİNE ETKİLERİNİN BELİRLENMESİ

THE USE OF FRUIT AND VEGETABLE WASTE COMPOST IN BASIL (OCIMUM BASILICUM L.) PLANT CULTIVATION AND ITS EFFECTS ON PLANT GROWTH

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ÖZET
Alışveriş merkezlerinde yoğun meyve ve sebze tüketimine bağlı olarak oluşan gıda atıkları, çevresel sorunlara yol açmakla birlikte yüksek organik madde içerikleri nedeniyle kompost üretimi için önemli bir hammadde kaynağıdır. Bu çalışmada, alışveriş merkezi kaynaklı meyve ve sebze atıklarından hızlı kompostlama yöntemiyle elde edilen kompostun fesleğen (*Ocimum basilicum* L.) gelişimi ve besin elementi alımı üzerine etkileri araştırılmıştır. Elde edilen kompost, toprakla hacim esasına göre %0, %25, %50, %75 ve %100 oranlarında karıştırılmış ve beş hafta inkübe edilmiştir. İnkübasyon öncesi ve sonrasında toprak, kompost ve karışımlar analiz edilmiştir. Daha sonra fesleğen fideleri saksılara aktarılmış ve kontrollü sera koşullarında beş tekerrürlü olarak yaklaşık 10 hafta yetiştirilmiştir. Hasat sonunda bitkilerde klorofil içeriği, kuru biyokütle ile makro [azot (N), fosfor (P), potasyum (K), kalsiyum (Ca), magnezyum (Mg)] ve mikro besin elementlerinin [bakır (Cu), demir (Fe), mangan (Mn) ve çinko (Zn)] konsantrasyonları belirlenmiştir. Kompost uygulamaları yetiştirme ortamının organik madde ve besin elementi düzeylerini önemli ölçüde artırmıştır. Bitki gelişimi açısından en uygun sonuçlar %25 kompost uygulamasında elde edilmiştir; bu uygulamada klorofil içeriği ve kuru biyokütle artmıştır. Kompost oranının %50 ve %75'e yükseltilmesi N, Ca ve P konsantrasyonlarını azaltırken K ve Zn konsantrasyonlarını artırmıştır. %100 kompost uygulamasında ise yüksek pH ve C/N oranı nedeniyle bitki gelişimi gerçekleşmemiştir. Sonuçlar, incelenen koşullarda %25 kompost ilavesinin fesleğen yetiştiriciliği için uygun olduğunu göstermiştir.
Anahtar Kelimeler: Alışveriş merkezlerinde gıda atıkları; hızlı kompostlama; fesleğen; bitkilerin besin alımı; organik atıkların değerlendirilmesi

ABSTRACT
Food waste generated in shopping malls as a result of intensive fruit and vegetable consumption poses environmental challenges; however, its high organic matter content makes it a valuable feedstock for compost production. This study investigated the effects of compost produced from shopping mall-derived fruit and vegetable waste using a rapid composting method on the growth and nutrient uptake of basil (*Ocimum basilicum* L.). The resulting compost was mixed with soil at volumetric rates of 0%, 25%, 50%, 75%, and 100%, followed by a five-week incubation period. Soil, compost, and their mixtures were analyzed before and after incubation. Basil seedlings were subsequently transplanted into pots and grown under controlled greenhouse conditions for approximately 10 weeks, with five replications per treatment. At harvest, chlorophyll content, dry biomass and the concentrations of macro [nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg)], and micronutrients [copper (Cu), iron (Fe), manganese (Mn), and zinc (Zn)] were determined in the plant tissues. Compost applications significantly increased the organic matter and nutrient levels of the growing medium. The most favorable plant growth responses were obtained with the 25% compost treatment, which increased chlorophyll content and dry biomass. Increasing the compost rate to 50% and 75% decreased N, Ca, and P concentrations while increasing K and Zn concentrations in the plants. In the 100% compost treatment, plant growth was inhibited, presumably due to the high pH and C/N ratio of the growing medium.

Overall, the results indicate that, under the conditions of this study, the incorporation of 25% compost is suitable for basil cultivation and represents a potential approach for the valorization of shopping mall-derived fruit and vegetable waste.
Keywords: Shopping mall food waste; rapid composting; basil; plant nutrient uptake; organic waste valorization

GİRİŞ

Dünyada ve ülkemizde gıda israfındaki artışla birlikte bu israfın ekonomik ve çevresel etkileri de artmaktadır. Her yıl küresel çapta yaklaşık 1,3 milyar ton gıda israf edilmekte ve bu da 1 trilyon doların üzerinde ekonomik kayıp anlamına gelmektedir (Beery ve ark., 2024). Dünya genelinde kişi başına düşen yıllık organik atık miktarı ülkeden ülkeye değişiklik göstermektedir. Birleşmiş Milletler Gıda ve Tarım Örgütü (FAO)'nun verilerine göre, Avrupa'da kişi başına düşen gıda atık miktarı ortalama 70-100 kg arasında değişirken, ABD'de bu miktar 120 kg'ı aşmaktadır (FAO, 2020). Türkiye'de ise kişi başına düşen yıllık gıda atık miktarının yaklaşık 93 kg olduğu belirtilmektedir (TÜİK, 2021). Evsel atıklar, gıda işleme tesisleri, tarımsal üretim, market ve alışveriş merkezleri meyve ve sebze satışı, hal kompleksleri, semt pazarları vb. alanlarda satış ve tüketiminin fazla olması nedeniyle büyük miktarda gıda atığı ya da organik atık üretilmektedir. Yüksek miktarlarda oluşan bu atıkların değerlendirilmesinde çeşitli yöntemler kullanılmaktadır. Bu yöntemlerden yakma, piroliz ve gazifikasyon gibi yöntemler çevresel açıdan daha fazla risk taşıyabilmektedir. Kompostlama ise, diğer atık yönetim tekniklerine kıyasla daha az enerji tüketen, daha az atık üreten ve ekonomik bir süreç olarak öne çıkmaktadır. Bu nedenle, entegre atık yönetimi sistemleri içerisinde kompostlama bir öncelik olarak değerlendirilmektedir. Türkiye'de üretilen atığın yaklaşık %50'sinin organik içerikli olduğu düşünüldüğünde, kompostlaştırma önemli ve etkin bir bertaraf yöntemi olarak öne çıkmaktadır. Kompost, organik atıkların kontrollü bir ortamda biyolojik olarak ayrıştırılması sonucu elde edilen organik bir toprak düzenleyicisidir (Acar ve Gülmez, 2021). Bu süreç, mikroorganizmaların etkisiyle organik materyalin ayrıştırılması ve besin maddelerinin toprağa geri kazandırılmasını sağlar (Kaya ve Yılmaz, 2020). Kompost sürecinin verimli ilerleyebilmesinde karbon/azot (C/N) dengesi, sıcaklık, nem seviyesi ve havalandırma koşulları gibi faktörler etkilidir (FAO, 2020). Kompost yapımında kullanılan kahverengi materyaller (sap, saman, talaş) karbon kaynağı sağlarken, yeşil materyaller (sebze-meyve atıkları, çim) ise azot kaynağı olarak sürece katkı sağlamaktadırlar (Songur, 2021). Kompostlaşma sürecinin hızlandırılması için organik materyallerin parçacık boyutunun küçültülmesi ve mikroorganizma aktivitesinin desteklenmesi önerilmektedir (Kaya ve Yılmaz, 2020).

Kompost yapımında soğuk kompost, sıcak kompost, bokaşi kompostu gibi farklı yöntemler geliştirilmiştir (FAO, 2020). Bu yöntemlerden farklı olarak, bu çalışmada hızlı kompostlama yöntemi kullanılmıştır. Hızlı kompostlama, biyolojik atıkların ısı ve nem kontrolü altında hızlı bir şekilde organik gübreye dönüştürülmesini sağlayan etkili bir yöntemdir. Bu yöntemde süreç, uygun mikroorganizmaların (bakteri ve funguslar gibi) aktivitesinin teşvik edilmesiyle hızlandırılır. Yapılan çalışmalar, yüksek aerobik koşullar altında gerçekleştirilen hızlı kompostlama süreçlerinin daha kısa sürede yüksek kaliteli kompost üretimi sağladığını göstermektedir. Kompostlaştırma ile atık azaltımı, kimyasal gübre kullanımının azaltılması, toprak verimliliğinin artırılması, karbon ayak izinin azaltılması (IPCC, 2021), toprak erozyonunun önlenmesi gibi birçok fayda sağlanabilmektedir (Palaniveloo ve ark., 2020).

Literatürde evsel, tarımsal ve gıda endüstrisi kaynaklı organik atıklardan elde edilen kompostların bitki gelişimi üzerine etkilerini inceleyen çok sayıda çalışma bulunmaktadır. Domates üretim artıklarından elde edilen kompostun toprağın organik maddesini artırdığı ve doğrudan bitki artıklarının uygulanmasına göre daha olumlu sonuçlar verdiği bildirilmiştir (Durmuş, 2019). Benzer şekilde, evsel organik atıklardan hazırlanan kompost uygulamalarının mısır ve biber bitkilerinde kuru madde üretimini ve N, P, K ve Ca alımını artırdığı rapor edilmiştir (Aynacı, 2015). Bender (2014) ise organik evsel atıklardan elde edilen kompostun biber bitkisinde meyve verimi ve meyve ağırlığını kompost dozuna bağlı olarak artırdığını bildirmiştir. Farklı organik atıklardan elde edilen kompostların bitki gelişimi üzerine etkilerini araştıran çalışmalar bulunmasına rağmen, alışveriş merkezlerinin market ve restoranlarından kaynaklanan meyve ve sebze atıklarının yeni bir teknik olan hızlı kompostlama yöntemiyle değerlendirilerek bitki yetiştiriciliğinde kullanım potansiyelini inceleyen herhangi bir

çalışmaya rastlanmamıştır. Bu durum, söz konusu organik atıkların sürdürülebilir tarım açısından değerlendirilmesine yönelik önemli bir araştırma boşluğunu ortaya koymaktadır.
Bu çalışmada bir alışveriş merkezinin marketinden açığa çıkan meyve ve sebze atıklarının yeni bir teknik olan hızlı kompostlama yöntemiyle değerlendirilmesi amaçlanmıştır. Çalışmada, bitki materyali olarak ballıbabagiller (Lamiaceae) familyasından tek yıllık ve genellikle ılıman bölgelerde yetişen fesleğen (*Ocimum basilicum*) bitkisi kullanılmıştır. Bu bitki görsel olarak güzel bir görünüme sahip, ekonomik değeri yüksek ve güzel kokulu aromatik bir bitkidir. Taze tüketim, baharat, tıbbi bitki ve süs bitkisi olarak yaygın şekilde yetiştirilmektedir (Daşgan ve ark., 2022). Bu özellikleri ve literatürde farklı kompost materyallerinin fesleğen bitkisi gelişimine etkisi konusunda çok az çalışma bulunması nedeniyle bitki materyali olarak fesleğen bitkisi seçilmiştir. Ayrıca, fesleğen bitkisinin gelişiminin yetiştirme ortamının fiziksel ve kimyasal özelliklerine duyarlı olması, farklı organik materyallerin yetiştirme ortamı olarak kullanım potansiyelinin değerlendirilmesinde bu bitkinin uygun bir model olarak kullanılmasına olanak sağlamaktadır.

MATERYAL VE YÖNTEM

Bitki materyali olarak Burgen tohum firmasından satın alınan yeşil fesleğen (reyhan) tohumu kullanılmıştır.
Hızlı Kompost Üretimi için Eskişehir ESPARK AVM'ye ait GEC (Green Enterprise & Co., Malezya) marka BMC-50 model hızlı kompostlama makinesi kullanılmıştır.
Denemede kullanılan toprak materyali Eskişehir Osmangazi Üniversitesi Ziraat Fakültesi deneme arazilerinden 0-30 cm derinlikten alınmıştır.

YÖNTEM

Toprak Hazırlığı

Saksı denemesi için araziden yaklaşık 100 kg toprak örneği alınmıştır. Laboratuvara getirilen toprak örneği, temiz bir naylon üzerine serilerek, taş ve bitki parçacıkları ayıklandıktan sonra kurumaya bırakılmıştır. Kuruyan toprak ufalanarak, 4 mm'lik elekten geçirilerek saksı denemelerinde kullanılmıştır. Toprak analizleri içinse 2 mm'lik elekten geçirilmiş toprak örneği kullanılmıştır. Deneme toprağı bazı fiziksel ve kimyasal analizler yapılmak üzere temiz polietilen kaba konularak laboratuvarda muhafaza edilmiştir.
Toprak örneklerinin analizleri, Eskişehir Geçit Kuşağı Tarımsal Araştırma Enstitüsü'nden hizmet alımı ile yapılmıştır. Toprak örneklerinin fiziksel ve kimyasal analizleri Tüzüner 1990'a göre aşağıdaki yöntemlere göre yapılmıştır:
Deneme toprağında tekstür hidrometre yöntemine göre (Bouyoucos 1962), toplam tuz, toprak reaksiyonu (Richards, 1954), kireç (Loeppert ve ark. 1996), alınabilir fosfor (Olsen ve ark., 1954) ve alınabilir potasyum (Richards, 1954) analizleri yapılmıştır.
Organik madde, Kacar (1995) tarafından bildirildiği şekilde modifiye Walkley-Black yöntemine göre tayin edilmiştir. Organik karbon (OK), organik maddenin (OM) yaklaşık %58'ini oluşturur. Analiz sonucunda Organik Madde (OM) değerinden Organik Karbonu (C) aşağıdaki formülle hesaplanmıştır:
% Organik Karbon (C)= % Organik Madde (OM) X 0.58
Toprak ve kompost örneklerinde toplam N analizi, Kjeldahl yöntemine göre Welp marka UDK 139 model Kjeldahl azot tayin cihazında belirlenmiştir (Kacar, 1995).
Toprağın yarayışlı formdaki Zn, Fe, Mn ve Cu içeriği DTPA (dietilentriaminpentaasetik asit) ekstraksiyon yöntemi (10 g toprak: 20 ml DTPA çözeltisi (0,005 M DTPA + 0,01 M $CaCI_2$ + 0,1 M TEA ve pH=7,3±0,05) ile (Lindsay and Norvell, 1978) belirlenmiştir ve analizinin doğruluğu için referans toprak kullanılarak test edilmiştir. Element konsantrasyonları PerkinElmer marka Optima 8000 model İndüktif Eşleşmiş Plazma Atomik Emisyon Spektroskopisi (ICP-OES)'de belirlenmiştir.

Kompost Üretimi

ESPARK AVM'de bulunan marketlerden çıkan meyve ve sebze atıkları önce parçalanarak 1-2 mm boyutlarına küçültülmüştür. Parçalanan atıklar 1/3 oranında talaşla karıştırılıp GEC (Green Enterprise & Co., Malezya) marka BMC-50 model hızlı kompostlama makinesinde bakteriler yardımıyla 24 saatte 75°C ile 100°C arasındaki sıcaklıkta ayrıştırılıp kompost haline getirilmiştir (Şekil 1).

Daha sonra analizleri yapılmış (Tablo 1) ve %0-25-50-75 ve 100 oranlarında toprak ve kompost karışımı hazırlanarak 5 hafta boyunca inkübasyona bırakılmıştır. İnkübasyon sonunda karışımlar saksı denemesinde kullanılmıştır.



Şekil 1. Kompost yapım aşamaları

Saksı Denemesi

Deneme Eskişehir Büyükşehir Belediyesi Park ve Bahçeler Daire Başkanlığı'na ait fidan üretim serasında yürütülmüştür. Sera sıcaklığı deneme boyunca gün içinde 25-30 °C, nem ise %85-90 arasında ölçülmüştür. Sera ışıklandırması 8 saat karanlık ve 16 saat aydınlık olacak şekilde ayarlanmıştır. Işık şiddeti 44-55 klux olarak ölçülmüştür.

Saksı denemesi için 4 mm'lik elekten elenmiş hava kuru toprak örneği kullanılmıştır. ESPARK AVM'den temin edilen meyve sebze atıkları ve talaş karışımından 24 saat süre içinde elde edilen kompost materyali analiz edildikten sonra;

%0 kompost+ %100 toprak
%25 kompost+%75 toprak
%50 kompost+ %50 toprak
%75 kompost+ %25 toprak
%100 kompost olarak karışımlar hazırlanıp 2 L'lik saksılara 1 kg karışım olarak doldurulmuş ve karışım 5 hafta süreyle inkübasyona bırakılmıştır (Şekil 2). Daha sonra analizler yapılmak üzere karışımlardan örnek alınmıştır.

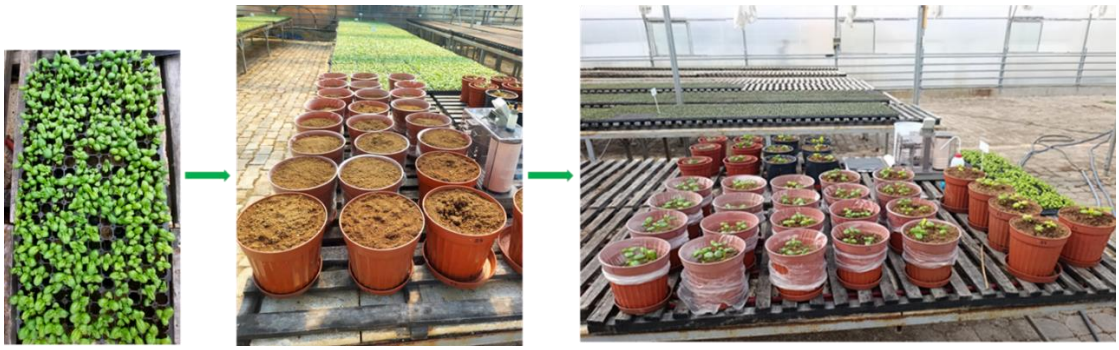


Şekil 2. Saksı denemesinin kurulumu ve inkübasyon aşaması

Ekimden önce karışımlardan alınan örneklerde Tablo 1'de belirtilen analizler yapıldıktan sonra analiz sonuçları dikkate alınarak her saksıya temel gübre olarak 200 ppm N (NH_4NO_3 formunda), 100 ppm P ve 125 ppm K (KH_2PO_4'ten), 2,5 ppm Fe (Fe-EDTA'dan) çözelti formunda toprağa ilave edilmiştir. Ancak N'nin yarısı başlangıçta, diğer yarısı ise denemenin 5. haftasında uygulanmıştır.

Fesleğen tohumları çimlendirme viyollerinde torf:perlit karışımında çimlendirildikten sonra (yaklaşık 1 ay) fideler 3-5 yapraklı dönemde iken saksılara aktarılmıştır.

Her saksıya 2 bitki olacak şekilde dikim yapılmış ve bitkiler 10 hafta yetiştirildikten sonra hasat edilmiştir. Deneme tek faktörlü tesadüf deneme parselleri deneme desenine göre 5 yinelemeli olarak kurulmuştur (Şekil 3).



Şekil 3. Saksı denemesinin kurulumu

Bitkiler saksıya aktarıldıktan sonra kompost uygulamalarının bitki gelişimi üzerine etkisine bağlı olarak yaklaşık 10 hafta süreyle yetiştirilmiştir. Denemede yapılan uygulamalar ile söz edilen gözlemlerdeki değişimler fotoğraflanarak görselleştirilmiştir.

Klorofil Analizi

Bitki yapraklarının klorofil içerikleri, Konica-Minolta SPAD-502 klorofil ölçüm cihazı kullanılarak belirlenmiştir.

Bitki Örneklerinin Hazırlanması ve Analizi

Deneme sonunda bitkiler toprak seviyesinin 1 cm üzerinde hasat edilip yaş ağırlıkları alındıktan sonra bitki örnekleri saf suyla yıkanıp kurutma dolabında 65 °C'de 48 saat kurutulmuştur. Bitkilerin kuru ağırlıkları alınarak bitki analizleri için bitki öğütme değirmeninde öğütülmüştür. Öğütülen bitki örneklerinden 0,2 g tartılarak üzerine 10 mL %65'lik HNO_3 ilave edilerek 45 dakika mikrodalga fırında (CEM marka Mars6 MarsXpress model) çözünürleştirilmiştir. Daha sonra saf su ile 20 ml'ye tamamlanmıştır. Element analizlerinin doğruluğu, element içeriği belli standart sertifikalı bir bitki (Virginia Tobacco Leaves (CTA-VTL-2)) örneğinin aynı yöntemle analiz edilmesi ile kontrol edilmiştir. Mikrodalga fırında çözünürleştirilen örneklerde toplam element konsantrasyonları (K, P, Ca, Mg, Zn, Cu, Fe ve Mn) ICP cihazında, toplam N ise Welp marka UDK 139 model Kjeldahl azot tayin cihazında belirlenmiştir. Bitki süzüntülerinden element okumaları Geçit Kuşağı Tarımsal Araştırma Enstitüsü'nden hizmet alımı ile gerçekleştirilmiştir. Bitki örneklerinde N analizi, Kjeldahl yöntemine göre Welp marka UDK 139 model Kjeldahl azot tayin cihazında belirlenmiştir (Kacar, 1995).

İstatistiksel Analiz

Araştırmadan elde edilen sonuçlar, SPSS istatistiksel analiz programından yararlanılarak varyans analizi ve ortalamalar arasındaki fark En Küçük Önemli Fark (LSD) testi uygulanarak gruplandırılmıştır.

BULGULAR ve TARTIŞMA

Deneme toprağının bazı fiziksel ve kimyasal özellikleri Tablo 1'de verilmiştir. Araştırmada kullanılan toprak killi tın bir bünyeye sahiptir. Deneme toprağı hafif alkali (7,76) reaksiyonlu, tuzsuz (1,02 dS/m) ve kireçli (%2,48) bir topraktır. Toprağın organik madde içeriği (%1,10) düşükken, toplam N (%0,11) miktarı yeterlidir. Alınabilir P (13,10 mg/kg) ve Cu (3,52 mg/kg) konsantrasyonları yeterliyken, K (875 mg/kg), Ca (6874 mg/kg) ve Mg (1008 mg/kg) konsantrasyonlarının fazla olduğu tespit edilmiştir. Demir konsantrasyonu (3,31 mg/kg) orta düzeydeyken, Zn (0,34 mg/kg) ve Mn (11,96 mg/kg) konsantrasyonları düşük olarak belirlenmiştir.

Tablo 1. Deneme toprağının bazı fiziksel ve kimyasal analiz sonuçları

Parametreler	**Birim**	**Analiz Yöntemi**	**Analiz Sonuçları**	**Değerlendirme**
Tekstür	%	Saturasyon Çamuru	51	Killi tın
pH			7,76	Hafif Alkali
Elektriksel İletkenlik (E.C)	dS/m		1,02	Tuzsuz
Kireç ($CaCO_3$)	%	Kalsimetre Yöntemi	2,48	Kireçli
Organik Madde (O.M.)	%	Walkley-Black Yaş Yakma Yöntemi	1,10	Az
% Organik Karbon (O.C)		%O.C= O.M.x 0,58	0,638	
% Toplam Azot (N)		Kjelhdal Yöntemi	0,11	Yeterli
C/N			5,8	
Fosfor (P)	mg/kg	Olsen Yöntemi	13,10	Yeterli
Potasyum (K)		Amonyum Asetat Yöntemi	875	Fazla
Kalsiyum (Ca)			6874	Fazla
Magnezyum (Mg)			1008	Fazla
Demir (Fe)		DTPA Ekstraksiyon Yöntemi	3,31	Orta
Bakır (Cu)			3,52	Yeterli
Çinko (Zn)			0,34	Az
Mangan (Mn)			11,96	Az

Kompost materyalinin analiz sonuçları

Meyve ve sebze atıklarından hızlı kompostlama yöntemi ile elde edilen kompost materyalinin kimyasal özellikleri Tablo 2'te verilmiştir. Kompost analiz sonuçları; 5 Mart 2015 tarihli 29286 sayılı Resmî Gazete'de yayımlanarak yürürlüğe giren ''Kompost Tebliği' 4. Bölüm 12 ve Ek 2'de yer alan kompost kalite parametrelerinde belirtilen değerler dikkate alınarak yorumlanmıştır. Bu tebliğe göre, hızlı kompostlama tekniğiyle elde edilen kompostun kullanılması için C/N oranının 10-30 aralığında, kuru madde içerisindeki organik maddenin %35'ten fazla, nem oranının ise %30'dan az ve mineral iyonlar hâlindeki tuzların 10 dS/cm'den az olması gerekmektedir. Bunlara ek olarak ''Kompost Tebliği"nde kompost ürününün pH değerinin 5,5-8,5 aralığında olması şartı aranmaktadır (Erdem ve ark., 2015).

Yukarıda belirtilen kriterlere göre elde edilen kompost kuvvetli alkali (9,55), tuzsuz (3,63 dS/cm), organik madde (%94,87) ve C/N oranı yüksek (46,63) olarak belirlenmiştir. Kjeldahl yöntemine göre toplam N konsantrasyonunun yüksek (%1,18) olduğu saptanmıştır. Mineral besin elementleri yönünden de oldukça zengin bir materyal olduğu belirlenmiştir.

Tablo 2. Kompost materyalinin bazı kimyasal analiz sonuçları

Parametreler	**Birim**	**Analiz Yöntemi**	**Analiz Sonuçları**	**Değerlendirme**
pH		1:2,5 Karışım Yöntemi	9,55	Kuvvetli Alkali
Elektriksel İletkenlik (EC)	dS/m		3,63	Tuzsuz
Organik Madde (O.M.)	%	Walkley-Black Yaş Yakma Yöntemi	94,87	Yüksek
Organik Karbon (O.C.)		% O.C.=O.M.*0,58	55,03	
Toplam Azot (N)		Kjeldahl Yöntemi	1,18	Yüksek
C/N			46,63	Yüksek
Fosfor (P)	%	Olsen Yöntemi	0,13	Çok fazla
Potasyum (K)		Amonyum Asetat Yöntemi	15,1	Çok fazla
Kalsiyum (Ca)			0,56	Fazla
Magnezyum (Mg)			0,25	Çok fazla

Demir (Fe)	mg/kg	TS ISO 14870 (DTPA Yöntemi)	948	Çok fazla
Bakır (Cu)			7,29	Çok fazla
Çinko (Zn)			32,2	Çok fazla
Mangan (Mn)			81,4	Fazla

İnkübasyon Sonucu Kompost analizleri

Kompost materyali artan oranlarda toprak materyali ile karıştırıldıktan sonra yaklaşık 5 hafta inkübasyona bırakılmıştır. İnkübasyon sonunda kimyasal özellikleri analiz edilerek sonuçlar Tablo 3'te sunulmuştur.

İnkübasyon sonunda kompost uygulamaları hafif alkalin ve tuzsuz özellik gösterirken, %100 kompost uygulaması kuvvetli alkalin ve hafif tuzlu özellik göstermiştir. Kompost ilavesi ile karışımların pH'sında artış gözlenmiştir. Karışımların kireç içerikleri, %25 uygulama dozu (orta kireçli) dışında kireçli sınıfta yer aldığı saptanmıştır.

Tablo 3. Toprak ve kompost karışımlarının inkübasyon sonunda bazı kimyasal analiz sonuçları

Kompost Uygulamaları	**pH**	**EC dS/m**	**Kireç (%)**	**OM (%)**	**N**	**C**	**C/N**
%0	7,79	0,66	3,96	1,03±0,08	0,09±0,01	0,59	6,99
%25	7,86	1,91	5,40	20,20±0,99	0,21±0,02	11,72	57,15
%50	7,89	3,00	3,60	42,30±0,86	0,51±0,02	24,53	48,58
%75	8,55	3,80	1,44	62,35±1,63	0,60±0,01	36,16	60,27
%100	9,56	4,49	-	93,48±1,17	1,21±0,19	54,22	44,99

Toprağın (%0 kompost), organik madde içeriği (%1,03) düşükken, kompost uygulamaları ile uygulama dozlarının organik madde içeriğinin arttığı ve yüksek düzeyde (>%4) olduğu belirlenmiştir. Toplam N konsantrasyonunun; %0 dozunda (%0,09-0,17) yeterli, %25 dozunda fazla (%0,17-0,32) ve diğer dozlarda ise çok fazla (>%0,32) olduğu belirlenmiştir.

Uygulamaların C/N oranının 10-30 aralığında olması beklenirken, %0 dozu dışındaki uygulamalarda C/N oranının >30 olduğu saptanmıştır. Kompostlaştırma sürecinin tamamlanıp tamamlanmadığına kompostun C/N oranına, oksijen ihtiyacına, sıcaklığına ve kokusuna bakılarak karar verilmektedir (Öztürk ve ark., 2010). Kompost materyalinde herhangi bir koku oluşmamış; oksijen ve sıcaklık makine tarafından otomatik olarak ayarlanmıştır. Ancak sonuçlardan da görüleceği gibi %0 dışındaki uygulamalarda kompost miktarındaki artışla birlikte düşük N ve yüksek C içerikleri nedeniyle C/N oranları yüksek çıkmıştır. Kompost uygulamalarında yüksek (>30) olan C:N oranını düşürmek için ortama N eklenmesi gerektiği sonucuna ulaşılmıştır (Öztürk ve ark., 2010). Songur (2021) tarafından yapılan çalışmada, kompostlaştırma sürecinde farklı karbon ve azot kaynaklarının etkisi araştırılmış ve karbon/azot oranının (C/N) 25-30 arasında tutulmasının mikrobiyal aktiviteyi optimize ettiği belirlenmiştir.

İnkübasyon sonunda uygulamaların makro besin elementi konsantrasyonları Tablo 4'te verilmiştir. Kalsiyum konsantrasyonlarının kompost uygulamalarıyla azaldığı ve yüksek düzeyde olduğu belirlenmiştir. Kompost uygulamaları ile K, Mg ve P konsantrasyonlarında artış gözlenmiştir. Potasyum, %0 dozunda yüksek düzeyde bulunurken, diğer dozlarda ise çok yüksek (>%0,1) düzeyde olduğu saptanmıştır.

Magnezyumun %100 dozunda çok yüksek düzeydeyken, diğer uygulamalarda yüksek değerlerde, alınabilir P ise %0 dozunda yeterli, %25 dozunda yüksek ve diğer dozlarda çok yüksek düzeylerde olduğu belirlenmiştir.

Tablo 4 Toprak ve kompost karışımlarının inkübasyon sonunda bazı makro besin elementleri konsantrasyonları

Kompost Uygulamaları	Ca (%)	K	Mg	P
%0	0,71±0,01	0,07±0,01	0,108±0,005	0,001±0,00
%25	0,53±0,02	0,25±0,01	0,139±0,01	0,007±0,00
%50	0,48±0,01	0,50±0,01	0,140±0,00	0,045±0,00
%75	0,35±0,003	0,80±0,03	0,114±0,005	0,037±0,001
%100	0,65±0,000	1,57±0,047	0,211±0,01	0,146±0,005

Uygulamaların mikro besin elementi konsantrasyonları Tablo 5'de verilmiştir. Kompost uygulamaları ile karışımların mikroelement konsantrasyonları artmıştır. Toprak ve kompost karışımlarının DTPA ile çözünebilir yarayışlı Cu konsantrasyonları yeterli, Fe konsantrasyonu %0 dozunda orta ve diğer dozlarda yüksek düzeylerde saptanmıştır.

Tablo 5. Toprak ve kompost karışımlarının inkübasyon sonunda bazı mikro besin elementleri konsantrasyonları

Kompost Uygulamaları	Cu (ppm)	Fe	Mn	Zn
%0	2,03±0,02	3,04±0,16	3,31±0,53	0,39±0,05
%25	2,50±0,05	7,42±0,95	63,99±1,56	1,39±0,14
%50	2,27±0,13	10,27±0,53	62,08±7,80	3,60±0,63
%75	2,51±0,03	16,81±1,20	65,58±1,94	4,55±0,41
%100	4,49±0,09	901±29,70	86,47±2,50	34,20±3,54

Yarayışlı Mn konsantrasyonları en düşük (3,04 ppm) %0 dozunda belirlenirken, dozlardaki artışla karışımlardaki Mn konsantrasyonu artmış ve yüksek düzeylerde belirlenmiştir. Yarayışlı Zn konsantrasyonunun %0 dozunda düşük seviyede, %25 dozunda yeterli, %50 ve %75 dozunda yüksek ve %100 dozunda ise çok yüksek seviyede olduğu saptanmıştır.

Klorofil içeriği ve Yeşil Aksam Kuru Ağırlığı

Denemede %100 kompost uygulamasında bitkiler gelişememiş ve büyüyememişlerdir. Kuruyarak ölen bitkilerden örnek alınamadığı için ölçümlerde bu doz değerlendirme dışı bırakılmıştır (Şekil 4).



Şekil 4. Saksı denemesi

Hasat öncesi bitkilerin gelişmesini henüz tamamlamış orta yapraklarında klorofil ölçümü yapılmıştır (Tablo 6). Tüm dozlarda saksılarda bitki gelişimi devam ederken %100 dozunda bitkiler gelişememiş ve kurumuştur (Şekil 4). En yüksek klorofil içerikleri %25 (37,4 SPAD birimi) ve %50 (35,6 SPAD birimi) kompost uygulamalarında ölçülmüştür.

Her iki uygulama klorofil içeriğine olumlu etki göstermiştir. Uygulamaların yaprak klorofil değerleri üzerindeki etkileri istatistiksel $p \leq 0,05$ düzeyinde önemli bulunmuştur.
Kompost uygulamalarının bitki yeşil aksamının kuru ağırlıklarına (KA) etkileri istatistiksel olarak %1 düzeyinde önemli bulunmuştur (Tablo 6). Kontrole kıyasla bitkilerde en fazla kuru ağırlık (0,66 g) %25 kompost uygulamasında elde edilmiştir.

Tablo 6. Kompost uygulamalarının fesleğen yaprakları klorofil içeriği ve kuru ağırlığına etkisi (n=5)

Dozlar	Klorofil İçeriği (SPAD Birimi)	KA (g/bitki)
%0	32,9b	0,55ab
%25	37,4a	0,66a
%50	35,6a	0,37bc
%75	31,9b	0,25c
F	15,5*	5,89**

(*): İstatistiksel olarak $p \leq 0.05$ düzeyinde önemli, (**): istatistiksel olarak $p \leq 0.01$ düzeyinde önemli bulunmuştur.
Benzer bulgular Aynacı (2015) ve Bender (2014) tarafından da rapor edilmiştir. Bender (2014), Çanakkale ilinin organik evsel atıklarından elde ettiği kompostu, 1/4, 2/4, 3/4, 4/4 oranlarında toprakla karıştırarak biber bitkisi yetiştirmiştir. Araştırmacı kompost dozundaki artışla birlikte sera koşullarında yetiştirilen biber bitkisinde meyve verimi, meyve sayısı ve tek meyve ağırlığında bir artış olduğunu rapor etmiştir. Aynacı (2015) evsel atıklardan hazırladığı kompost uygulamalarındaki artışla mısır ve biber bitkilerinin kuru ağırlığının arttığını bildirmiştir.
Nocentini ve ark. (2024), turba yerine kullanılabilecek biokömür ve kompostun iki farklı fesleğen çeşidinin verimi ve uçucu yağ profili üzerindeki etkilerini araştırdıkları çalışmada, ağaçların budama atıklarından elde ettikleri biochar ve ev mutfak atıklarından hazırlanan kompost kullanılarak, ticari turba (torf) ile farklı oranlarda karıştırılmış ortamlarda ve farklı dozlarda N uygulayarak saksılarda yetiştirilen fesleğen bitkisinin büyümesi ve uçucu bileşen içeriklerini incelemişlerdir. Saf biyokömür veya kompost uygulamasının muhtemelen yetiştirme ortamının pH'sının ve elektrik iletkenliğinin çok yüksek olması nedeniyle fide ölümüne neden olduğu tespit edilmiştir. Bununla birlikte, biyokömürün (%25) ve kompostun (%25 veya %50) torf ile karıştırıldığı ortamlarda bitkilerin geliştiği, ancak taze kütle ve yaprak rengi açısından fesleğen için ticari standartları garanti edemediği saptanmıştır.

Besin elementi Konsantrasyonları

Artan dozlarda kompost uygulamaları ile bitki dokularının besin elementi konsantrasyonları değişkenlik göstermiş ve sonuçlar istatistiksel olarak anlamlı bulunmuştur (Tablo 7). Bitki dokularında belirlenen makro besin elementi içerikleri incelendiğinde, uygulamaların tüm parametreler üzerinde istatistiksel olarak anlamlı etkiler oluşturduğu görülmektedir ($p \leq 0.05$). Bu durum kompost dozunun bitki beslenme dengesini önemli ölçüde değiştirdiğini göstermektedir.
Bitki azot içeriği %2,95–4,38 arasında değişmiştir. En yüksek toplam N konsantrasyonu (%4,38) %25 kompost uygulamasından elde edilirken, kontrol uygulaması da %4,31 N konsantrasyonu ile aynı istatistiksel grupta yer almıştır. Uygulamalardaki artışla bitki dokularındaki N konsantrasyonu azalmıştır. Buna karşılık, kompost oranının %50 ve %75'e yükseltilmesi azot içeriğinde önemli düşüşlere neden olmuştur. Özellikle %75 dozunda azot içeriği kontrol uygulamasına göre yaklaşık %32 oranında azalmıştır. Kompostun yüksek dozlarda uygulanması, başlangıçta yüksek karbon içeriğine bağlı mikrobiyal immobilizasyonu artırarak bitki tarafından alınabilir azot miktarını sınırlandırmış olabilir. Ayrıca hızlı gelişen bitkilerde görülen "seyrelme etkisi" de dokudaki azot konsantrasyonunun azalmasına katkıda bulunmuş olabilir. Kompostun olgunlaşma döneminde mevcut N'nin mikroorganizmalarca protein kaynağı olarak kullanılması nedeniyle bitkinin yararlanabileceği N konsantrasyonunda azalmaya neden olabilir. Beş haftalık inkübasyon sonunda, temel gübre olarak verilen N, kompostun olgunlaşmasını tamamlamamış olabileceğinden dolayı mikroorganizmalar tarafından kullanılarak ortamda N azalmış olabilir.
Kalsiyum ve P konsantrasyonları kompost uygulamaları ile azalırken, K konsantrasyonu artış göstermiştir. Magnezyum konsantrasyonu ise yalnızca %75 kompost uygulamasında azalmıştır.

Kompost uygulamalarının bitki dokularındaki makro besin elementi konsantrasyonları üzerindeki etkileri istatistiksel olarak %5 düzeyinde önemli bulunmuştur.

Tablo 7. Kompost uygulamalarının fesleğen bitkisi yeşil aksam besin elementi konsantrasyonlarına etkisi (n=5)

Dozlar	N (%)	Ca	K	Mg	P	Cu (ppm)	Fe	Mn	Zn
%0	4,31a	3,02a	3,47d	0,77a	0,68a	14,0a	136a	123a	10,3d
%25	4,38a	2,00b	5,48c	0,75a	0,50ab	14,8a	70,3b	99,1ab	18,8c
%50	3,37b	1,55b	7,06b	0,81a	0,34b	4,81b	42,6c	82,6bc	23,0b
%75	2,95b	0,66c	12,83a	0,38b	0,31b	3,89b	69,5b	62,8c	28,5a
F	10,6*	38,2*	119*	27,4*	5,19**	39,8*	183*	9,33*	58,8*

(*): İstatistiksel olarak $p \leq 0.05$ düzeyinde önemli, (**):İstatistiksel olarak $p \leq 0.01$ düzeyinde önemli bulunmuştur.

Fesleğen bitkisinin yeşil aksamının makro besin elementlerinin yeterlilik düzeyleri Clade ve ark. (2025)'e göre aşağıda değerlendirilmiştir. Uygulamaların %0 ve %25 dozlarında N bitkiler için yeterli düzeyde (%4,13-5,54) bulunurken, %50 ve %75 dozlarında düşük düzeyde (%2,63-4,13) olduğu saptanmıştır. Kalsiyum değerleri % 0,66 ile 3,02 arasında değişim göstermiş olup, 75 dozu dışında Ca bitkiler için yeterli düzeyde (%1,53-2,11) bulunmuştur. Benzer durum Mg konsantrasyonlarında da gözlenmiş; 75 kompost uygulama dozunda bitkilerde Mg düşük (%0,29-0,52) düzeydeyken, diğer dozlarda Mg bitkiler için yeterli düzeyde (%0,52-0,88) olduğu belirlenmiştir.
Bitki dokularının P konsantrasyonları %0,31-0,68 arasında değişmiştir. Kontrol ve %0 ve %25 dozlarında P bitkiler için yeterli düzeyde (%0,50-1,01) bulunurken, %50 ve %75 dozlarında düşük düzeyde (%0,21-0,50) olduğu saptanmıştır.
Kompost uygulamalarının bitki dokularının mikrobesin elementi konsantrasyonlarına etkisi istatistiksel olarak $p \leq 0.01$ düzeyinde önemli bulunmuştur (Tablo 10). En yüksek Cu konsantrasyonu sırasıyla %25 kompost ve kontrol uygulamalarında belirlenirken, diğer dozlarda azalma olmuştur. Demir ve Mn konsantrasyonları uygulamalarla azalmıştır. Diğer yandan, en yüksek Zn konsantrasyonu (28,5 ppm) %75 kompost uygulamasında saptanmıştır; bu değer kontrol uygulamasına göre 2,8 kat daha fazladır.
Benzer sonuçlar Aynacı (2015) tarafından da bildirilmiştir. Araştırmacı, evsel kompost uygulaması ile biber bitkisinin N konsantrasyonunda 2-2,4 kat artış olduğunu, ayrıca hem mısır hem de biber bitkisinin P, K ve Ca konsantrasyonlarının kompost miktarı artışından olumlu yönde etkilendiğini tespit etmiştir.
Fesleğen bitkisinin yeşil aksam mikro besin elementlerinin yeterlilik düzeyleri Clade ve ark., (2025)'e göre aşağıda değerlendirilmiştir. Bakır değerleri 3,89-14,8 ppm arasında değişim göstermiş olup, %75 dozu dışında Cu bitkiler için yeterli düzeyde (4,3-16,6 ppm) bulunmaktadır. En yüksek (136 ppm) ve yeterli Fe konsantrasyonu %0 uygulamasından elde edilirken, kompost uygulamaları ile bitkilerin Fe konsantrasyonları, %50 dozu (noksan) dışında, düşük (51,0-83,1 ppm) düzeyde olduğu saptanmıştır. En yüksek Mn konsantrasyonu %0 uygulamasından (123 ppm) elde edilmiştir. Kompost uygulamaları ile bitki dokularında Mn konsantrasyonları azalmış, ancak bitkiler için yeterli düzeyde (58,4-132,6 ppm) olduğu tespit edilmiştir. Bitki dokularının Zn konsantrasyonu kontrol bitkisinde noksanlık düzeyindeyken, kompost uygulamaları ile Zn konsantrasyonunun artış göstermesine rağmen düşük düzeyde olduğu belirlenmiştir.

SONUÇ

Bu çalışmada AVM meyve ve sebze atıklarından hızlı kompostlama yöntemi ile elde edilen kompostun fesleğen bitkisinin büyüme ve gelişmesine etkileri araştırılmıştır. Böylece gıda atıklarının değerlendirilmesi, elde edilecek kompostun alternatif yetiştirme ortamı olarak kullanılabilirliğinin araştırılması ve sıfır atık fikri ile çevresel bir sorun olan AVM'nin sebze ve meyve atıklarının geri dönüşümünün sağlanması hedeflenmiştir.
Kompost uygulamalarındaki artışla inkübasyon sonunda pH, tuz ve organik madde miktarları artış göstermiştir. Kalsiyum dışında makro (N, K, P ve Mg) ve mikro (Fe, Cu, Mn ve Zn) element konsantrasyonlarında artış gözlenmiştir.

Elde edilen bulgular, hızlı kompostlama yöntemi ile hazırlanan kompostun yetiştirme ortamının organik madde ve besin elementi içeriğini önemli ölçüde artırdığını göstermiştir. Bununla birlikte, kompost uygulama dozu bitki gelişimi üzerinde belirleyici olmuştur ve tüm dozlar aynı düzeyde olumlu sonuç vermemiştir. Elde edilen kompostun ve uygulamaların C/N oranı yüksek olmakla birlikte, gelecekte yapılacak çalışmalarda bu oran N uygulaması ile 10-30 aralığına düşürülebilir. Uygulamalarda ağır metal konsantrasyonları yasal düzenlemelerde belirtilen değerlere uymuştur ve herhangi bir toksik etki görülmemiştir.

Araştırmada en yüksek klorofil içeriği ile kuru biyokütle değerleri %25 kompost uygulamasında elde edilmiştir. Bu dozun fesleğen gelişimi açısından en uygun uygulama olduğu belirlenmiştir.

Daha yüksek kompost oranlarında özellikle N, Ca ve P konsantrasyonlarının azalması, buna karşılık K ve Zn konsantrasyonlarının artması, kompost dozunun bitki beslenme dengesini önemli ölçüde değiştirdiğini göstermektedir. Saf kompost ortamında bitki gelişiminin gerçekleşmemesi ise hızlı kompost ürününün tek başına yetiştirme ortamı olarak kullanılmasının uygun olmadığını ortaya koymuştur.

Elde edilen sonuçlar, hızlı kompostlama ile üretilen kompostun doğrudan yetiştirme ortamı olarak değil, uygun oranlarda toprakla karıştırılarak kullanılmasının daha güvenli ve daha verimli olduğunu göstermektedir. İncelenen koşullar altında yaklaşık %25 kompost uygulaması bitki gelişimi açısından en uygun doz olarak belirlenmiştir. Ancak daha sonra yapılacak çalışmalarda %25 dozu temel alınarak daha düşük dozların etkileri araştırılmalıdır.

Bu çalışma, alışveriş merkezlerinden kaynaklanan organik atıkların katma değeri yüksek bir ürüne dönüştürülebileceğini ve döngüsel ekonomi ile sürdürülebilir atık yönetimi yaklaşımlarına katkı sağlayabileceğini ortaya koymaktadır. Bununla birlikte, hızlı kompostlama ile elde edilen ürünün tarımsal kullanımının daha kapsamlı değerlendirilebilmesi için kompost olgunluk kriterlerinin, mikrobiyolojik stabilitenin ve farklı bitki türleri ile farklı toprak koşullarındaki uzun dönem etkilerinin gelecekte yapılacak çalışmalarla desteklenmesi yararlı olacaktır.

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STİREN VE SAF AKRİLİK EMÜLSİYONLARININ TEMİZLENEBİLİRLİK VE FOTOOKSİDATİF BOZULMA PERFORMANSLARININ KARŞILAŞTIRMALI ANALİZİ

COMPARATIVE ANALYSIS OF THE CLEANABILITY AND PHOTO-OXIDATIVE DEGRADATION PERFORMANCE OF STYRENE AND PURE ACRYLIC EMULSIONS

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ÖZET

Küresel kaplama endüstrisinin 2025 yılı itibarıyla 220 milyar USD pazar büyüklüğüne ulaşması ve AB 2004/42/EC Direktifi kapsamında VOC salım sınırlamalarının giderek sıkılaşması, su bazlı bağlayıcı teknolojilerine olan talebi hızla artırmaktadır. Bu çalışma; yüksek cam geçiş sıcaklığına (Tg) sahip saf akrilik homopolimer emülsiyonu (HB-A) ile yerli üretim metil metakrilat–etil metakrilat–stiren (MMA–EMA–S) kopolimer emülsiyonu (HB-B) bağlayıcı sistemlerini, dış cephe boya performansı ekseninde çok parametreli ve performansa dayalı bir yaklaşımla karşılaştırmayı amaçlamaktadır.

Her iki bağlayıcı sistemi kullanılarak %35–45 pigment hacim konsantrasyonu (PVC) aralığında rutil TiO_2 ve kalsit içeren su bazlı boya formülasyonları hazırlanmıştır. Dispersiyon stabilitesi ve reolojik davranış reometre (EN ISO 3219-2:2021) ile Brookfield viskozimetre (ISO 2555:2018) kullanılarak değerlendirilmiştir. Yüzey ıslanabilirliği ve yüzey enerjisi temas açısı ölçümleriyle (ISO 19403-2:2017), su taşınım özellikleri ise su buharı difüzyon katsayısı tayiniyle (EN ISO 7783-1:2018) karakterize edilmiştir. Film performansı; parlaklık (EN ISO 2813:2014), ıslak silme dayanımı/temizlenebilirlik (EN ISO 11998) ve çatlak köprüleme (BS EN 1062-7:2004) testleriyle nicelleştirilmiştir. Fotooksidatif bozulma davranışı ASTM G154 QUV hızlandırılmış yaşlandırma ve Xenon ark yöntemiyle incelenmiş; ΔE*, parlaklık kaybı ve yüzey kusur verileri doğal yaşlandırma sonuçlarıyla (EN 927-3:2019) birlikte yorumlanmıştır.

Çalışma sonucunda, HB-B kopolimer sisteminin zincir yapısındaki segmental dağılım ve stiren katkısının etkisiyle daha yüksek UV dayanımı, daha düşük su difüzyonu ve geliştirilmiş yüzey temizlenebilirliği sağladığı gözlemlenmiştir. Temizlenebilirlik–su difüzyonu–fotooksidatif yaşlanma ilişkisini moleküler ağırlık dağılımı (MWD), zincir sonu fonksiyonelliği ve hidroksil grup etkisi üzerinden bütüncül olarak ilişkilendiren "yapı–taşınım–performans" çerçevesini oluşturmaktadır. Sürdürülebilirlik değerlendirmesi ISO 14040/44 uyumlu yaşam döngüsü analizi (LCA) ile entegre edilmiş; ithal HB-A (A1–A3: 2257 g CO_2-eşd./L) ile yerli HB-B (A1–A3: 1946 g CO_2-eşd./L) senaryoları cradle-to-grave sistem sınırlarında kıyaslanmıştır. Fonksiyonel birim 1 m² dış cephe yüzeyi için 15 yıl referans ve 20 yıl duyarlılık senaryosu olarak tanımlanmıştır.

Elde edilen bulgular; HB-B bağlayıcısının mekanik esneklik, UV dayanımı ve lojistik kaynaklı karbon ayak izi avantajlarını bir arada sunduğunu, yerli kopolimer formülasyonunun hem performans hem de çevresel sürdürülebilirlik kriterleri açısından rekabetçi bir alternatif oluşturduğunu ortaya koymaktadır. Sonuçlar, bağlayıcı seçimi ve reçete optimizasyonuna yönelik veri temelli karar destek çerçevesi sunmakta; endüstriyel ölçekte ticarileştirme ve yayın/patent süreçleri için sistematik bir altyapı sağlamaktadır.

Anahtar Kelimeler: Su bazlı boya, akrilik emülsiyon, kopolimer bağlayıcı, fotooksidatif yaşlanma, LCA, temizlenebilirlik, dış cephe performans

ABSTRACT

The global coatings industry reached an estimated market value of USD 220 billion in 2025, and the progressive tightening of VOC emission limits under EU Directive 2004/42/EC has substantially accelerated demand for waterborne binder technologies. This study aims to comparatively evaluate a high glass transition temperature (Tg) pure acrylic homopolymer emulsion (HB-A) and a domestically produced methyl methacrylate–ethyl methacrylate–styrene (MMA–EMA–S) copolymer emulsion (HB-B) binder system through a multi-parametric, performance-driven approach within the context of exterior architectural coating applications.

Waterborne paint formulations containing rutile TiO_2 and calcite fillers at a pigment volume concentration (PVC) range of 35–45% were prepared using both binder systems. Dispersion stability and rheological behavior were assessed by rotational rheometry (EN ISO 3219-2:2021) and Brookfield viscometry (ISO 2555:2018). Surface wettability and surface energy were characterized via contact angle measurements (ISO 19403-2:2017), while water transport properties were determined through water vapor diffusion coefficient testing (EN ISO 7783-1:2018). Film performance was quantified by gloss measurements (EN ISO 2813:2014), wet scrub resistance and cleanability testing (EN ISO 11998), and crack bridging evaluation (BS EN 1062-7:2004). Photooxidative degradation behavior was examined by ASTM G154 QUV accelerated weathering and xenon arc exposure; colorimetric stability (ΔE^*), gloss retention, and surface defect data were interpreted in conjunction with natural weathering results (EN 927-3:2019).

The results demonstrated that the HB-B copolymer system, owing to its segmental distribution along the polymer backbone and the contribution of the styrene monomer, exhibited superior UV resistance, reduced water diffusion, and enhanced surface cleanability. The study establishes a "structure–transport–performance" framework that holistically correlates cleanability, water diffusion, and photooxidative aging through molecular weight distribution (MWD), chain-end functionality, and hydroxyl group influence. Sustainability assessment was integrated through a life cycle analysis (LCA) conducted in accordance with ISO 14040/44; the imported HB-A scenario (A1–A3: 2257 g CO_2-eq/L) and the domestically produced HB-B scenario (A1–A3: 1946 g CO_2-eq/L) were compared within cradle-to-grave system boundaries. The functional unit was defined as 1 m² of exterior façade surface over a 15-year reference service life, with a 20-year sensitivity scenario.

The findings indicate that the HB-B binder simultaneously offers advantages in mechanical flexibility, UV durability, and reduced logistics-related carbon footprint, establishing the domestically produced copolymer formulation as a competitive alternative in terms of both technical performance and environmental sustainability criteria. The results provide a data-driven decision support framework for binder selection and formulation optimization, while offering a systematic foundation for industrial-scale commercialization as well as publication and patent application processes.

Keywords: Waterborne coating; acrylic emulsion; copolymer binder; photooxidative aging; life cycle assessment (LCA); cleanability; exterior façade performance

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FARKLI GÖRÜNTÜ ÇÖZÜNÜRLÜKLERİNİN DERİN ÖĞRENME TABANLI KÜÇÜK NESNE TESPİTİ PERFORMANSINA ETKİSİNİN KARŞILAŞTIRMALI ANALİZİ

COMPARATIVE ANALYSIS OF THE IMPACT OF DIFFERENT IMAGE RESOLUTIONS ON DEEP LEARNING-BASED SMALL OBJECT DETECTION PERFORMANCE

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ÖZET

Derin öğrenme tabanlı nesne tespit yöntemleri, son yıllarda endüstriyel kalite kontrol, üretim hattı denetimi, yüzey kusuru tespiti, güvenlik ve savunma sistemleri ile otonom sürüş gibi geniş bir uygulama yelpazesinde kritik bir rol üstlenmiştir. Bununla birlikte, görüntü içerisinde az sayıda piksel ile temsil edilen küçük boyutlu nesnelerin veya hataların tespiti, konvolüsyon katmanlarındaki ardışık örnekleme (downsampling) işlemleri sonucunda öznitelik haritalarında bilgi kaybı yaşanması nedeniyle model performansını ciddi biçimde sınırlayan, literatürde hâlâ açık bir problem olarak kabul edilen önemli bir zorluk teşkil etmektedir.

Bu çalışmada, söz konusu problemi ele almak amacıyla YOLO mimarisinin farklı giriş görüntü çözünürlükleri altındaki davranışı sistematik ve deneysel bir yaklaşımla incelenmiştir. Bu doğrultuda, aynı veri seti ve aynı hiperparametre konfigürasyonu (öğrenme oranı, batch size, epoch sayısı, veri artırma teknikleri) sabit tutularak, model sırasıyla 320, 640, 960 ve 1280 piksel gibi farklı çözünürlük (imgsize) değerleri ile yeniden eğitilmiştir. Böylece çözünürlük dışındaki değişkenlerin sonuçlar üzerindeki etkisi minimize edilerek, imgsize parametresinin izole bir şekilde değerlendirilmesi hedeflenmiştir. Her bir eğitim senaryosu için elde edilen modellerin performansı; genel tespit başarımını yansıtan metrikler üzerinden değerlendirilmiş; ayrıca özellikle küçük nesne kategorisine ait tespit oranları ayrı olarak raporlanmıştır. Bunlara ek olarak, her çözünürlük seviyesinin pratik uygulanabilirliğini ortaya koymak amacıyla eğitim süresi, çıkarım (inference) süresi, GPU bellek kullanımı ve model boyutu gibi hesaplama maliyeti göstergeleri de karşılaştırmalı olarak sunulmuştur.

Elde edilen deneysel bulgular, giriş görüntü çözünürlüğünün artırılmasının, özellikle küçük nesnelerin ayırt edici özniteliklerinin daha fazla piksel ile temsil edilmesini sağlayarak tespit doğruluğunu belirgin biçimde iyileştirdiğini göstermektedir; ancak bu iyileşme, eğitim ve çıkarım süresindeki artış ile donanım kaynak tüketimindeki yükseliş gibi önemli maliyetler karşılığında elde edilmektedir. Buna karşın, düşük çözünürlüklü konfigürasyonların gerçek zamanlı işlem hızı açısından avantaj sağladığı, fakat küçük nesnelerin tespitinde belirgin bir doğruluk kaybına yol açtığı gözlemlenmiştir. Çalışma kapsamında elde edilen bu bulgular ışığında, her bir çözünürlük seviyesinin avantaj ve dezavantajları sistematik bir şekilde ortaya konulmuş; gerçek zamanlı çalışması gereken düşük gecikmeli sistemler ile yüksek hassasiyet gerektiren kalite kontrol uygulamaları gibi farklı senaryolar için en uygun imgsize seçimine yönelik somut ve uygulanabilir öneriler sunulmuştur. Bu yönüyle çalışma, hem akademik literatüre hem de endüstriyel uygulayıcılara, model tasarımı sürecinde çözünürlük-performans dengesini optimize etmeleri için pratik bir referans noktası sağlamayı amaçlamaktadır.

Anahtar Kelimeler: Derin Öğrenme, Görüntü İşleme, Kalite Kontrol, Görüntü Çözünürlüğü, Optimizasyon, Nesne Tespit Performansı

ABSTRACT

Deep learning-based object detection methods have recently played a critical role in a wide range of applications such as industrial quality control, production line inspection, surface defect detection, security and defense systems, and autonomous driving. However, detecting small-sized objects or defects represented by only a few pixels in an image remains a major challenge. This difficulty arises due to information loss in feature maps caused by successive downsampling operations in convolutional layers, and it is still considered an open problem in the literature.

In this study, the behavior of the YOLO architecture under different input image resolutions was systematically and experimentally examined to address this problem. Using the same dataset and identical hyperparameter configurations (learning rate, batch size, number of epochs, data augmentation techniques), the model was retrained with varying resolution (imgsize) values of 320, 640, 960, and

1280 pixels. By keeping all other variables constant, the effect of the imgsize parameter was isolated for evaluation. The performance of each training scenario was assessed using metrics reflecting overall detection accuracy, with special emphasis on detection rates for small object categories. Additionally, computational cost indicators such as training time, inference time, GPU memory usage, and model size were comparatively reported to highlight the practical applicability of each resolution level.
Experimental findings demonstrate that increasing input image resolution significantly improves detection accuracy for small objects by enabling their distinctive features to be represented with more pixels. However, this improvement comes at the expense of increased training and inference times as well as higher hardware resource consumption. Conversely, lower-resolution configurations provide advantages in real-time processing speed but lead to notable accuracy losses in small object detection. Based on these results, the advantages and disadvantages of each resolution level were systematically presented, and concrete, practical recommendations were offered for selecting the most suitable imgsize in different scenarios—such as low-latency systems requiring real-time operation versus quality control applications demanding high precision. In this respect, the study aims to provide both academic researchers and industrial practitioners with a practical reference point for optimizing the resolution-performance trade-off in model design.
Keywords: Deep Learning, Image Processing, Quality Control, Image Resolution, Optimization, Object Detection Performance

1. GİRİŞ

Bilgisayarla görü alanında son on yılda kaydedilen ilerlemeler, derin öğrenme tabanlı nesne tespit yöntemlerinin endüstriyel üretim süreçlerine entegrasyonunu hızlandırmış ve otomatik görsel muayene sistemlerini geleneksel, kural tabanlı görüntü işleme yaklaşımlarının yerine geçirecek bir olgunluk seviyesine taşımıştır. Özellikle konvolüsyonel sinir ağları (CNN) üzerine inşa edilen tek aşamalı (one-stage) tespit mimarileri, hem yüksek doğruluk hem de gerçek zamanlı çalışabilme kapasitesi sunmaları nedeniyle üretim hattı denetimi, montaj doğrulama, yüzey kusuru tespiti ve parça sayımı gibi görevlerde yaygın biçimde tercih edilmektedir. Bu mimariler arasında You Only Look Once (YOLO) ailesi, tespit görevini tek bir ileri beslemeli sinir ağı geçişi ile gerçekleştirebilmesi sayesinde, hem araştırma camiasında hem de endüstriyel uygulayıcılar tarafından fiili bir standart hâline gelmiştir [1][2][3].
Bununla birlikte, nesne tespiti alanındaki başarıya rağmen, küçük nesnelerin tespiti hâlâ çözülmemiş, literatürde geniş biçimde tartışılan bir problem olmaya devam etmektedir. Bir nesnenin "küçük" olarak sınıflandırılması, genellikle görüntü çözünürlüğüne göre normalize edilmiş piksel alanı ile ilişkilendirilir; örneğin MS COCO gibi yaygın referans veri kümelerinde 32×32 pikselden küçük nesneler küçük nesne kategorisinde değerlendirilmektedir [4]. Konvolüsyonel sinir ağlarının omurga (backbone) katmanlarında gerçekleştirilen ardışık örnekleme (downsampling / stride) işlemleri, öznitelik haritalarının uzamsal çözünürlüğünü aşamalı olarak azaltmakta; bu durum, zaten sınırlı sayıda pikselle temsil edilen küçük nesnelerin ayırt edici özniteliklerinin derin katmanlara ulaşana kadar büyük ölçüde kaybolmasına yol açmaktadır. Sonuç olarak, model, küçük nesneleri arka plandan ayırt edebilecek yeterli uzamsal ve anlamsal bilgiye derin katmanlarda sahip olamamakta, bu da düşük geri çağırma (recall) ve yüksek yanlış negatif oranlarıyla kendini göstermektedir.
Bu problemin pratik önemi, özellikle hassas toleranslara sahip endüstriyel kalite kontrol uygulamalarında daha da belirginleşmektedir. Bu çalışmanın uygulama bağlamını oluşturan örnek olayda soğuk plaka (cold plate) üretiminde kullanılan alüminyum gövdeler üzerindeki diş onarım elemanlarının, yani Helicoil'lerin, doğru şekilde monte edilip edilmediğinin görsel olarak denetlenmesi hedeflenmektedir. Helicoil, vida dişleri zayıf ya da hasar görmüş malzemelere -özellikle alüminyum gibi yumuşak metallere- sağlam ve dayanıklı dişler kazandırmak amacıyla kullanılan bir diş onarım (telli diş burcu) elemanıdır. Helicoil montaj işleminin ardından, ilgili delikte bulunan Helicoil'in montaj tırnağının kırılarak tırnaksız hâle getirilmesi gerekmektedir; kalite prosedürleri gereğince, Helicoil bulunmayan (Helicoil Yok) ya da tırnağı kırılmamış (Tırnaklı) durumların her ikisi de geçersiz kabul edilmektedir. Bu üç durumun -Helicoil Yok, Tırnaklı ve Tırnaksız- otomatik olarak ve yüksek güvenilirlikle ayırt edilmesi, hem üretim kalitesini garanti altına almak hem de manuel muayenenin neden olduğu işçilik maliyetini ve insan kaynaklı hata payını azaltmak açısından büyük önem taşımaktadır. Bunla beraber ilgili görsel kusurların görüntüdeki karşılığı yalnızca birkaç piksellik bir alanla sınırlı kalabilmekte; bu da problemi tipik bir küçük nesne tespiti senaryosuna dönüştürmektedir.

Küçük nesne tespiti probleminin çözümüne yönelik literatürde çok sayıda yaklaşım önerilmiştir: çok ölçekli öznitelik piramitleri (Feature Pyramid Network), dikkat (attention) mekanizmaları, veri artırma stratejileri, ek tespit katmanlarının eklenmesi ve mimari düzeyde yapılan değişiklikler bunlardan bazılarıdır. Ancak bu yaklaşımların büyük bölümü, model mimarisinde köklü değişiklikler gerektirmekte ve dolayısıyla ek geliştirme, eğitim ve bakım maliyeti getirmektedir. Buna karşın, giriş görüntüsünün çözünürlüğünü (imgsize) artırmak, mevcut bir model mimarisinde herhangi bir yapısal değişiklik gerektirmeyen, uygulaması en basit ve en doğrudan yöntemlerden biri olarak öne çıkmaktadır. Görüntü çözünürlüğünün artırılması, küçük nesnelerin ağ girişinde daha fazla piksel ile temsil edilmesini sağlayarak, teorik olarak öznitelik haritalarındaki bilgi kaybını telafi edebilmektedir. Ancak bu kolaylığın bir bedeli vardır: çözünürlüğün artırılması, hesaplama maliyetini karesel olarak artırmakta; bu durum eğitim süresini, çıkarım gecikmesini ve GPU bellek tüketimini doğrudan etkilemektedir. Dolayısıyla, pratikte karşılaşılan asıl soru "çözünürlüğü artırmak faydalı mıdır?" sorusu değil, "çözünürlük artışının getirdiği doğruluk kazanımı, ödenen hesaplama maliyetini hangi noktada haklı çıkarmaktadır?" sorusudur.

Bu çalışma, tam olarak bu soruya sistematik ve deneysel bir çerçevede yanıt aramaktadır. Çalışmada, YOLO tabanlı bir nesne tespit modeli, veri seti, hiperparametreler, veri artırma stratejisi, başlangıç ağırlıkları ve eğitim çizelgesi (epoch/optimizer) sabit tutularak yalnızca giriş çözünürlüğü (imgsize) parametresi değiştirilmek suretiyle dört farklı senaryoda (320, 640, 960 ve 1280 piksel) yeniden eğitilmiş; elde edilen modellerin genel ve küçük nesneye özgü tespit performansı ile hesaplama maliyeti göstergeleri karşılaştırmalı olarak analiz edilmiştir. Bu şekilde, imgsize parametresinin etkisi diğer değişkenlerden izole edilerek, çözünürlük-performans dengesine ilişkin literatüre ve endüstriyel uygulayıcılara somut, tekrarlanabilir ve doğrudan uygulanabilir bulgular sunulması amaçlanmıştır.

2. KURAMSAL ÇERÇEVE VE İLGİLİ ÇALIŞMALAR

2.1. Derin Öğrenme Tabanlı Nesne Tespiti

Nesne tespiti, bir görüntü içerisindeki nesnelerin konumunu sınırlayıcı kutular (bounding box) ile belirlemeyi ve her bir nesneyi ilgili sınıfa atamayı amaçlayan bir bilgisayarla görü görevidir. Derin öğrenme öncesi dönemde bu görev, elle tasarlanmış öznitelik çıkarıcılar (HOG, SIFT gibi) ve kayan pencere (sliding window) yaklaşımlarıyla gerçekleştirilirken, konvolüsyonel sinir ağlarının 2012 sonrasında görüntü sınıflandırma görevlerinde elde ettiği başarı, nesne tespiti alanına da hızla taşınmıştır. Literatürde nesne tespit mimarileri genel olarak iki ana kategoriye ayrılmaktadır: (i) iki aşamalı (two-stage) yaklaşımlar, aday bölge üretimi ve sınıflandırma adımlarını ayrı ayrı gerçekleştiren R-CNN ailesi modelleri (R-CNN, Fast R-CNN, Faster R-CNN) [5] [6] (ii) tek aşamalı (one-stage) yaklaşımlar, aday bölge üretimi ve sınıflandırmayı tek bir ağ geçişinde birleştiren SSD ve YOLO ailesi modelleridir [1] [7]. İki aşamalı yöntemler genellikle daha yüksek doğruluk sunarken, tek aşamalı yöntemler daha düşük gecikme ve daha yüksek çıkarım hızı sağlamaktadır; bu nedenle gerçek zamanlı çalışması gereken endüstriyel uygulamalarda tek aşamalı mimariler tercih sebebi olmaktadır.

YOLO mimarisi, görüntüyü ızgara (grid) hücrelerine bölerek her hücrenin sınırlı sayıda sınırlayıcı kutu, sınıf olasılığı ve güven skoru tahmin etmesi ilkesine dayanır. İlk sürümünden bu yana YOLO ailesi; omurga ağının derinleştirilmesi, çok ölçekli tespit katmanlarının (FPN/PAN benzeri yapılar) eklenmesi [8], çapasız (anchor-free) tespit stratejilerine geçiş ve eğitim sürecindeki veri artırma ile kayıp fonksiyonu iyileştirmeleri [9] gibi pek çok yönden evrim geçirmiştir [2] [3].Güncel YOLO sürümleri, hem doğruluk hem de çıkarım hızı bakımından dengeli bir performans sunmaları nedeniyle endüstriyel görsel muayene sistemlerinde yaygın olarak tercih edilmektedir.

2.2. Küçük Nesne Tespiti Problemi

Küçük nesne tespiti, nesne tespiti literatüründe bağımsız bir alt alan olarak ele alınacak kadar önemli bir problemdir. Bu zorluğun temel kaynağı, konvolüsyonel omurga ağlarındaki ardışık örnekleme işlemleridir: bir görüntü ağ içerisinde ilerledikçe uzamsal boyutları küçülmekte (tipik olarak 8, 16, 32 kat örnekleme adımlarıyla), bu süreçte küçük nesnelere ait uzamsal bilgi derin katmanlara ulaşana kadar büyük ölçüde kaybolmaktadır. Örneğin 8 kat örnekleme uygulayan bir katmanda, orijinal görüntüde 16×16 piksel büyüklüğündeki bir nesne, öznitelik haritasında yalnızca 2×2 piksellik bir alana karşılık gelmekte; bu da modelin nesneyi arka plan gürültüsünden ayırt edebilmesi için gerekli bağlamsal bilgiyi önemli ölçüde sınırlamaktadır.

Ayrıca küçük nesnelerin veri kümelerinde nadir örneklenmesi ve sınırlayıcı kutu konumlandırma hatalarının küçük nesnelerde IoU (Intersection over Union) metriğini orantısız biçimde düşürmesi de bu problemi derinleştiren ek etkenlerdir [10] [11].

Literatürde bu problemin çözümüne yönelik başlıca yaklaşımlar; çok ölçekli öznitelik füzyonu sağlayan öznitelik piramidi ağları (Feature Pyramid Network) [8], yüksek çözünürlüklü öznitelik haritalarını koruyan mimari tasarımlar, küçük nesnelere ek ağırlık veren kayıp fonksiyonu düzenlemeleri [9], kopyala-yapıştır (copy-paste) tabanlı veri artırma teknikleri ve görüntü çözünürlüğünün artırılması olarak sınıflandırılabilir [10]. Bu çalışma, söz konusu yaklaşımlar arasında en az mimari müdahale gerektiren ve endüstriyel ortamlarda en kolay uygulanabilen yöntem olan giriş görüntü çözünürlüğünün artırılması stratejisine odaklanmakta ve bu stratejinin fayda-maliyet dengesini deneysel olarak nicelendirmeyi amaçlamaktadır.

2.3. Giriş Çözünürlüğünün Model Performansına Etkisi

Giriş görüntü çözünürlüğü (imgsize), derin öğrenme tabanlı nesne tespit modellerinde hem doğruluk hem de hesaplama maliyeti üzerinde doğrudan belirleyici bir hiperparametredir; nitekim omurga derinliği, genişliği ve girdi çözünürlüğünün birlikte ölçeklendirildiği bileşik ölçekleme (compound scaling) çalışmaları da çözünürlüğün doğruluk-maliyet dengesindeki bu belirleyici rolünü nicel olarak ortaya koymaktadır [12]. Bir görüntünün doğrusal boyutu (kenar uzunluğu) S faktörü ile ölçeklendirildiğinde, görüntüdeki toplam piksel sayısı -dolayısıyla ağın işlemesi gereken veri hacmi- yaklaşık olarak S^2 oranında artmaktadır. Bu ilişki, konvolüsyon katmanlarının hesaplama karmaşıklığına doğrudan yansımakta; FLOP (kayan noktalı işlem) sayısı ve buna bağlı olarak eğitim süresi, çıkarım gecikmesi ve GPU bellek gereksinimi de benzer şekilde karesel olarak artmaktadır. Öte yandan, çözünürlük artışı, görüntüdeki her bir nesnenin ağ girişinde temsil edildiği piksel sayısını da aynı oranda artırmakta; bu durum özellikle küçük nesneler için kritik önem taşımaktadır, çünkü nesnenin ayırt edici kenar, doku ve şekil özniteliklerinin öznitelik haritalarında korunabilmesi, o nesnenin yeterli sayıda piksel ile temsil edilmesine bağlıdır.

Bu çalışmada kullanılan referanslama yaklaşımına göre, 320 piksel taban alınarak diğer çözünürlükler bu referansa göre normalize edilmiştir. Buna göre 640 piksel, 320 pikselin 2 katı kenar uzunluğuna ve 4 katı piksel alanına; 960 piksel, 3 katı kenar uzunluğuna ve 9 katı piksel alanına; 1280 piksel ise 4 katı kenar uzunluğuna ve 16 katı piksel alanına karşılık gelmektedir. Görüntülerin en-boy oranının korunması amacıyla letterbox (kenar dolgulu) yeniden boyutlandırma yöntemi kullanıldığında, dolgu işlemi ölçekleme katsayısı uygulandıktan sonra devreye girmekte ve nesnenin ağ girişindeki görünür alanı, ölçek faktörünün karesiyle orantılı biçimde büyümektedir. Bu teorik ilişki, çalışmanın Bölüm 5.2'sinde ele alınan gerçek nesne geometrisi analizinin de temelini oluşturmaktadır.

3. AMAÇ VE KAPSAM

Bu çalışmanın temel amacı, derin öğrenme tabanlı bir nesne tespit modelinin (YOLO mimarisi) giriş görüntü çözünürlüğüne (imgsize) karşı gösterdiği davranışı, kontrollü ve tekrarlanabilir bir deney tasarımı çerçevesinde sistematik olarak incelemek ve özellikle küçük nesne tespiti bağlamında çözünürlük-performans-maliyet dengesini nicel olarak ortaya koymaktır. Çalışmanın alt amaçları aşağıdaki şekilde özetlenebilir:

- Aynı veri seti, aynı model mimarisi ve aynı hiperparametre konfigürasyonu altında, yalnızca giriş çözünürlüğünün (320, 640, 960, 1280 piksel) değiştirilmesiyle elde edilen model performansındaki değişimi ölçmek;
- Genel tespit başarımının yanı sıra, özellikle küçük nesne kategorisine ait tespit oranlarının çözünürlükle nasıl değiştiğini incelemek;
- Her çözünürlük seviyesinin eğitim süresi, çıkarım gecikmesi, kare hızı (FPS) ve GPU bellek kullanımı gibi hesaplama maliyeti göstergeleri açısından karşılaştırmalı olarak değerlendirmek;
- Gerçek nesne geometrisi üzerinden (piksel bazlı) teorik bir analiz yaparak, çözünürlük artışının küçük nesnelerin ağ girişindeki temsiline olan etkisini nicel biçimde açıklamak;
- Farklı uygulama senaryoları (gerçek zamanlı/düşük gecikmeli sistemler ile yüksek hassasiyet gerektiren kalite kontrol uygulamaları) için en uygun imgsize seçimine yönelik somut öneriler geliştirmek.

Çalışmanın kapsamı, endüstriyel bir kalite kontrol senaryosu olan Helicoil diş onarım elemanlarının montaj durumunun (Helicoil Yok, Tırnaklı, Tırnaksız) görsel olarak otomatik tespiti ile sınırlandırılmıştır. Bu senaryo, soğuk plaka (cold plate) üretiminde alüminyum gövdeler üzerinde gerçekleştirilen bir kalite denetim adımını temsil etmekte olup hedef nesnelerin (Helicoil montaj bölgeleri) görüntü içerisinde görece küçük bir alan kaplaması nedeniyle küçük nesne tespiti problemi için gerçekçi ve temsil edici bir uygulama alanı oluşturmaktadır. Çalışma kapsamında yalnızca giriş çözünürlüğü parametresi değişken olarak ele alınmış; model mimarisi, omurga ağı, veri artırma stratejisi, optimizasyon algoritması ve eğitim süresi (epoch sayısı) gibi diğer tüm değişkenler sabit tutulmuştur. Bu sınırlama, elde edilen bulguların yalnızca çözünürlük etkisine atfedilebilmesini sağlamak amacıyla bilinçli olarak yapılmıştır.

4. MATERYAL VE YÖNTEM

4.1. Uygulama Alanı: Helicoil Kalite Kontrolü

Çalışmanın uygulama bağlamını, soğuk plaka (cold plate) ürünlerinin üretim sürecindeki bir kalite kontrol adımı oluşturmaktadır. Bu ürünlerde, alüminyum gövdeler üzerindeki vida dişlerinin dayanıklılığını artırmak amacıyla Helicoil adı verilen telli diş yayları kullanılmaktadır. Helicoil, özellikle alüminyum gibi görece yumuşak ve aşınmaya duyarlı malzemelerde, zayıf ya da hasar görme riski taşıyan vida dişlerine sağlam ve dayanıklı bir diş yapısı kazandırmak için delik içerisine yerleştirilen paslanmaz çelik bir elemandır.

Helicoil montaj işleminin standart prosedürüne göre, montajın ardından delikte bulunan Helicoil'in üst kısmındaki montaj tırnağının (takma/çıkarma amaçlı kullanılan uzantı) kırılarak uzaklaştırılması ve elemanın "tırnaksız" hâle getirilmesi gerekmektedir. Kalite prosedürleri açısından üç farklı delik durumu tanımlanabilir: (i) Helicoil Yok – deliğe hiç Helicoil takılmamış durum, (ii) Tırnaklı – Helicoil takılmış ancak montaj tırnağı henüz kırılmamış durum, (iii) Tırnaksız – Helicoil doğru şekilde takılmış ve tırnağı kırılarak nihai, kabul edilebilir hâle getirilmiş durum. Bu tanımlara göre yalnızca "Tırnaksız" durum kalite prosedürü açısından geçerli kabul edilmekte; "Helicoil Yok" ve "Tırnaklı" durumların her ikisi de hatalı olarak sınıflandırılmaktadır. Sınıflara yönelik örnek görsel Şekil 1'de gösterilmiştir. Bu üç sınıfın yüzlerce delikten oluşan bir gövde üzerinde manuel olarak, çıplak gözle ve tutarlı biçimde ayırt edilmesi, hem zaman alıcı hem de insan kaynaklı hataya açık bir süreçtir; dolayısıyla bu sürecin derin öğrenme tabanlı bir görsel tespit sistemiyle otomatikleştirilmesi hedeflenmiştir.



Şekil 1. Delik tipleri

4.2. Veri Seti

Çalışmada kullanılan veri seti, ilgili üretim hattından toplanan fotoğraflardan oluşturulmuştur. Toplam 682 adet fotoğraf üzerinden etiketleme çalışması gerçekleştirilmiş olup, veri seti eğitim (train), doğrulama (validation) ve test alt kümelerine ayrılmıştır. Veri setinin dağılımı Tablo 1'de özetlenmiştir.

Alt Küme	Görüntü Sayısı	Oran (%)
Eğitim (Train)	478	%70
Doğrulama (Validation)	136	%20
Test	68	%10
Toplam	682	%100

Tablo 1. Veri Seti Dağılımı

Sınıf düzeyinde incelendiğinde veri setinde üç hedef durum etiketlenmiştir: 24.498 örnekte Helicoil Yok, 6.718 örnekte Tırnaklı ve 3.807 örnekte Tırnaksız durumu gözlemlenmiştir. Veri seti sınıflar arasında tam dengeli bir dağılım göstermemektedir. Bununla birlikte, bu dağılım üretim sürecinde karşılaşılan gerçek durum frekanslarını yansıtmakta olup veri toplama aşamasında uygulama senaryosunun temsil edilebilirliğini korumak amacıyla bilinçli olarak muhafaza edilmiştir. Böylece modelin, sahada karşılaşacağı veri dağılımına uygun şekilde eğitilmesi hedeflenmiştir. Veri setinin çeşitliliğini ve modelin genelleme kabiliyetini artırmak amacıyla, veri artırma (data augmentation) yöntemi olarak görüntülere farklı gain (parlaklık/kazanç) değerleri uygulanmıştır. Bu yaklaşım, delik ve Helicoil bölgelerinin farklı aydınlatma ve görüntüleme koşullarında da tutarlı biçimde tespit edilebilmesini sağlamak amacıyla tercih edilmiştir. Tüm çözünürlük senaryolarında aynı veri bölünmesi, aynı augmentasyon seti ve aynı örnekler kullanılmış; bu sayede veri kaynaklı farklılıkların deney sonuçlarını etkilemesi engellenmiştir.

4.3. Ölçekleme ve Piksel Alanı İlişkisi

Model eğitimi öncesinde, girdi görüntüleri her bir imgsize senaryosuna (320, 640, 960, 1280 piksel) uygun biçimde yeniden boyutlandırılmıştır. Yeniden boyutlandırma işlemi, görüntünün en-boy oranını koruyacak şekilde letterbox yöntemiyle gerçekleştirilmiş; kısa kenarda oluşan boşluklar sabit renkli dolgu ile tamamlanmıştır. Bu yaklaşımın seçilmesinin nedeni, nesne geometrisinin bozulmasını (deformasyonunu) önlemek ve farklı çözünürlükler arasında nesnelerin göreli boyut oranlarının tutarlı kalmasını sağlamaktır.

320 piksel referans alındığında, 640, 960 ve 1280 piksel çözünürlükleri sırasıyla referansın 2, 3 ve 4 katı kenar uzunluğuna karşılık gelmektedir. Görüntü doğrusal olarak S katı büyütüldüğünde, görüntüdeki toplam piksel alanı (ve dolayısıyla her bir nesnenin kapladığı piksel alanı) yaklaşık olarak S^2 katı artmaktadır. Buna göre 640 piksel, referansın 4 katı; 960 piksel, 9 katı; 1280 piksel ise 16 katı piksel alanına karşılık gelmektedir. Bu ilişki, hem modelin nesneleri temsil etme kapasitesini hem de gerekli hesaplama kaynağını doğrudan etkilemesi bakımından çalışmanın merkezi teorik dayanağını oluşturmaktadır ve Bölüm 5.2'de gerçek nesne ölçüleri üzerinden nicel olarak değerlendirilmiştir.

4.4. Model Mimarisi

Deneylerde, tek aşamalı (one-stage), çapa tabanlı/çapasız modern varyantlarıyla bilinen YOLO ailesinden bir nesne tespit modeli kullanılmıştır. Model, omurga (backbone), boyun (neck) ve tespit başı (head) olmak üzere üç temel bileşenden oluşmaktadır: omurga katmanları girdi görüntüsünden hiyerarşik öznitelikler çıkarmakta, boyun kısmı farklı ölçeklerdeki öznitelik haritalarını (çok ölçekli öznitelik piramidi mantığıyla) birleştirmekte, tespit başı ise her ölçekteki öznitelik haritası üzerinden sınıf olasılığı, güven skoru ve sınırlayıcı kutu koordinatlarını tahmin etmektedir. Modelin çok ölçekli tespit yapısı, teorik olarak farklı boyutlardaki nesnelerin (küçük, orta, büyük) farklı çözünürlükteki öznitelik haritaları üzerinden tespit edilmesine imkân tanımakta; ancak küçük nesnelere karşılık gelen yüksek çözünürlüklü öznitelik haritalarının bilgi içeriği, girdi çözünürlüğü düşük olduğunda ciddi biçimde sınırlanmaktadır.

4.5. Deney Tasarımı

Çalışmanın deney tasarımı, imgsize parametresinin etkisini izole biçimde ölçebilmek amacıyla kontrollü bir yaklaşımla kurgulanmıştır. Bağımsız değişken, $S \in \{320, 640, 960, 1280\}$ kümesinden alınan giriş çözünürlüğü değeridir. Bağımlı değişkenler ise mAP50, mAP50–95, precision, recall gibi genel tespit başarım metrikleri ile gecikme (ms), kare hızı (FPS), GPU bellek kullanımı (VRAM) ve eğitim süresi gibi hesaplama maliyeti göstergeleridir. Tekrarlanabilirliği sağlamak amacıyla dört çözünürlük senaryosunda da; aynı veri bölünmesi, aynı başlangıç ağırlıkları, aynı seed (rastgelelik tohumu) seti, aynı veri artırma stratejisi ve aynı epoch sayısı/optimizer konfigürasyonu kullanılmıştır. Ölçüm güvenilirliğini artırmak amacıyla her koşul için en az 3 farklı seed ile eğitim tekrarlanmış ve sonuçlar ortalama ± standart sapma biçiminde raporlanacak şekilde tasarlanmıştır. Deney tasarımının şematik özeti Tablo 2'de sunulmuştur.

Bileşen	Açıklama
Bağımsız değişken	Giriş çözünürlüğü S ∈ {320, 640, 960, 1280} piksel
Bağımlı değişkenler	mAP50, mAP50–95, Precision, Recall, AP_small, gecikme, FPS, VRAM, eğitim süresi
Sabit tutulan değişkenler	Veri bölünmesi, başlangıç ağırlığı, seed seti, augmentasyon, epoch sayısı, optimizer
Tekrar sayısı	Her koşul için ≥ 3 seed; ortalama ± standart sapma raporu

Tablo 2. Deney Tasarımı Özeti

4.6. Değerlendirme Metrikleri

Model performansının değerlendirilmesinde nesne tespiti literatüründe yaygın olarak kullanılan standart metrikler benimsenmiştir. mAP50 (mean Average Precision @ IoU=0.50), tahmin edilen sınırlayıcı kutular ile gerçek (ground truth) kutular arasında en az %50 örtüşme (IoU) şartı altında modelin genel tespit başarısını ifade etmekte; göreli olarak toleranslı bir doğruluk ölçütü sunmaktadır. mAP50–95 ise IoU eşiğinin 0,50'den 0,95'e kadar 0,05 aralıklarla artırılmasıyla elde edilen ortalama değerleri ifade etmekte olup sınırlayıcı kutu konumlandırma hassasiyetini de dikkate alan, daha katı ve kapsamlı bir başarı göstergesidir. Precision (P), modelin ürettiği tüm pozitif tahminler içerisinde doğru tespitlerin oranını; Recall (R) ise veri setindeki gerçek nesnelerin ne kadarının model tarafından başarıyla yakalandığını göstermektedir. Küçük nesne tespiti bağlamında recall metriği özellikle kritik önem taşımaktadır, zira düşük recall değeri, kalite kontrol uygulamalarında hatalı (Helicoil Yok veya Tırnaklı) parçaların gözden kaçırılması anlamına gelmekte ve bu durum üretim güvenilirliği açısından kabul edilemez bir risk oluşturmaktadır.

Hesaplama maliyeti göstergeleri olarak; bir görüntünün işlenmesi için geçen toplam çıkarım süresi (T_{FPS}, milisaniye cinsinden), saniyedeki kare sayısı (FPS), eğitim ve çıkarım sırasında kullanılan GPU bellek miktarı (VRAM, gigabayt cinsinden) ve bir eğitim döngüsünün tamamlanması için gereken toplam süre (saat cinsinden) raporlanmıştır. Bu göstergeler, elde edilen doğruluk kazanımının pratik uygulanabilirlik açısından ne ölçüde sürdürülebilir olduğunu değerlendirmek amacıyla kullanılmıştır.

5. BULGULAR VE TARTIŞMA

5.1. Genel Performans Sonuçları

Dört farklı imgsize senaryosunda (320, 640, 960, 1280 piksel) elde edilen model performansı ve hesaplama maliyeti göstergeleri Tablo 3'te karşılaştırmalı olarak sunulmuştur.

imgsz	mAP50	mAP50–95	P	R	Gecikme (ms)	FPS	VRAM (GB)	Eğitim (saat)
320	%89,4	%70,9	%81,8	%83,9	80,1	12,48	0,08	0,026
640	%98,9	%89,2	%96,0	%96,4	85,8	11,65	0,09	0,035
960	%98,9	%91,3	%96,4	%97,2	97,6	10,24	0,14	0,073
1280	%99,0	%92,1	%96,5	%96,8	109,2	9,15	0,21	0,089

Tablo 3. Çözünürlük (imgsize) Senaryolarına Göre Model Performansı ve Hesaplama Maliyeti

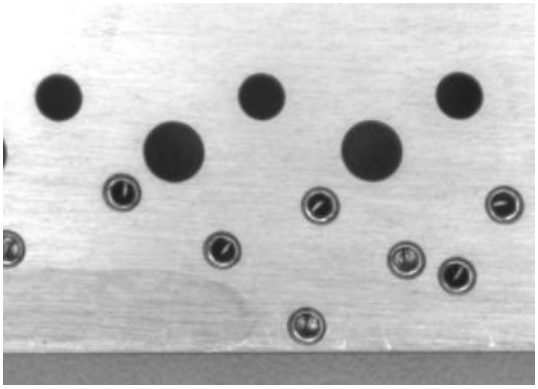
Tablo 3'teki bulgular incelendiğinde, giriş çözünürlüğünün 320 pikselden 1280 piksele yükseltilmesiyle mAP50 değerinin %89,4'ten %99,0'a, mAP50–95 değerinin %70,9'dan %92,1'e ve recall değerinin %83,9'dan %96,8'e yükseldiği görülmektedir. Bu artış eğilimi özellikle 320'den 640 piksele geçişte belirgin bir sıçrama göstermekte; mAP50–95 değeri bu aralıkta 18,3 puan artmaktadır (%70,9 → %89,2).

Buna karşın 640'tan 960'a ve 960'tan 1280'e geçişlerde performans artışı belirgin biçimde yavaşlamakta, mAP50–95 değeri sırasıyla yalnızca 2,1 ve 0,8 puan artmaktadır. Bu örüntü, çözünürlük-performans ilişkisinin doğrusal olmadığını, aksine azalan getiriler (diminishing returns) prensibine uygun bir doyum (saturasyon) eğrisi izlediğini ortaya koymaktadır: model, belirli bir eşik çözünürlüğün (bu çalışmada yaklaşık 640 piksel) üzerinde, artan çözünürlükten elde ettiği marjinal fayda giderek azalan bir performans kazanımı elde etmektedir; bu bulgu, bileşik ölçekleme çalışmalarında bildirilen benzer doyum eğilimleriyle de örtüşmektedir [12].

Hesaplama maliyeti tarafında ise ilişki büyük ölçüde tekdüze (monoton) ve beklenen yönde artmaktadır: çıkarım gecikmesi 80,1 ms'den 109,2 ms'ye yükselmekte (yaklaşık %36 artış), buna karşılık FPS değeri 12,48'den 9,15'e gerilemektedir (yaklaşık %27 azalış). VRAM kullanımı 0,08 GB'den 0,21 GB'ye çıkarak yaklaşık 2,6 kat artmakta; eğitim süresi ise 0,026 saatten 0,089 saate yükselerek yaklaşık 3,4 kat büyümektedir. Eğitim süresindeki bu artış oranının, teorik S^2 ilişkisinin öngördüğü değerlere (16 katına kadar) kıyasla daha ılımlı kalması, kullanılan donanımın düşük çözünürlüklerde tam kapasiteyle çalışmaması, batch işleme verimliliği ve bellek bant genişliği sınırlamaları gibi pratik etkenlerle açıklanabilir; buna karşın eğilimin yönü teorik beklentiyle tümüyle tutarlıdır.

5.2. Gerçek Nesne Geometrisine Göre Çözünürlük Analizi

Çözünürlük artışının küçük nesne tespitine olan etkisini yalnızca genel performans metrikleri üzerinden değil, aynı zamanda gerçek nesne geometrisi üzerinden de nicel olarak açıklamak amacıyla, veri setindeki orijinal görüntü boyutu (3088×2075 piksel) ve tipik bir Helicoil/delik bölgesinin gerçek boyutu (75×75 piksel) temel alınarak bir ölçekleme analizi gerçekleştirilmiştir. Şekil 2'de veri setinde yer alan orijinal görüntü boyutu yer almaktadır. Bu analizde, orijinal görüntüdeki delik alanının toplam görüntü alanına oranı yaklaşık %0,0878 olarak hesaplanmış; bu oran, hedef nesnenin görüntü içerisinde oldukça küçük bir alanı kapladığını açıkça ortaya koymaktadır.

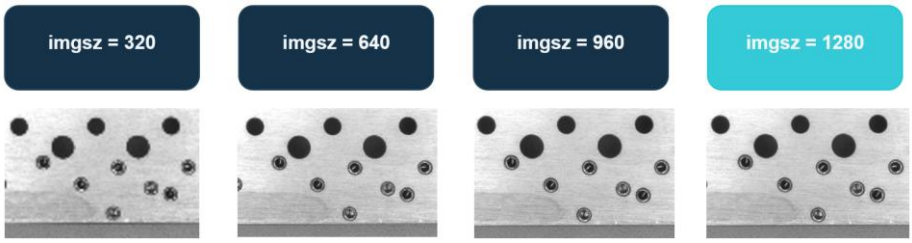


Şekil 2. Veri setinde yer alan orijinal görüntü (3088×2075 piksel)

Ölçekleme katsayısı s = imgsize / 3088 olarak tanımlandığında, delik kenar uzunluğu 75×s, delik alanı ise $5.625 \times s^2$ formülüyle hesaplanmaktadır. Çözünürlük 320'den 1280 piksele (4 kat) yükseltildiğinde, delik kenar uzunluğu da 4 kat artmakta; alan ise kenar uzunluğunun karesiyle orantılı olarak yaklaşık 16 kat büyümektedir. Bu ilişki, konvolüsyon ağlarının tipik 8 kat (stride 8) örnekleme yapan ilk tespit katmanı referans alınarak da değerlendirilmiş; her çözünürlük seviyesinde delik bölgesinin öznitelik haritasındaki karşılığının kaç "hücre"ye denk geldiği hesaplanmıştır. Elde edilen sonuçlar Tablo 4'te sunulmuştur.

Ayrıca Şekil 3'te aynı görüntü bölgesinin 320, 640, 960 ve 1280 piksel çözünürlüklerdeki karşılıkları gösterilmektedir. Görsel inceleme sonuçları, çözünürlük arttıkça Helicoil ve delik bölgesini tanımlayan kenar geçişlerinin daha belirgin hale geldiğini ortaya koymaktadır. Özellikle 320 piksel çözünürlükte delik içerisindeki geometrik detaylar sınırlı sayıda piksel ile temsil edildiğinden helicoil tespiti oldukça zorlaşmaktadır.. Çözünürlüğün 640 piksele yükseltilmesiyle birlikte delik sınırları daha net biçimde ayrışmakta ve bölgesel detaylar belirginleşmektedir. 960 ve 1280 piksel çözünürlüklerde ise Helicoil yapısına ilişkin ince geometrik özellikler, kenar sürekliliği ve doku bilgisi daha yüksek doğrulukla korunabilmektedir. Bu durum, hedef nesnenin görüntü içerisinde temsil edildiği piksel sayısının artmasıyla doğrudan ilişkilidir.

Dolayısıyla çözünürlük artışı yalnızca nesne alanını büyütmekle kalmamakta, aynı zamanda modelin ayırt edici öznitelikleri öğrenebilmesi için gerekli olan görsel bilginin korunmasına da katkı sağlamaktadır. Elde edilen bulgular, Tablo 4'te sunulan ölçekleme analizini görsel olarak desteklemekte ve çözünürlük artışına bağlı performans iyileşmesinin temel nedenlerinden birinin nesne detaylarının daha yüksek mekânsal çözünürlükte temsil edilmesi olduğunu göstermektedir.



Şekil 3. Farklı çözünürlüklere göre veri seti görüntüleri

imgsz	Görüntü İçeriği (px)	Delik Boyutu (px)	Delik Alanı (px^2)	Stride-8 Hücre Sayısı	Göreli Maliyet
320	320 × 215	7,77 × 7,77	60,40	0,97	0,25×
640	640 × 430	15,54 × 15,54	241,62	1,94	1×
960	960 × 645	23,32 × 23,32	543,64	2,91	2,25×
1280	1280 × 860	31,09 × 31,09	966,47	3,89	4×

Tablo 4. Gerçek Nesne Geometrisine Göre Çözünürlük Bazlı Piksel ve Maliyet Analizi

Tablo 4'teki sonuçlar, çalışmanın en kritik bulgularından birini görsel/geometrik açıdan doğrulamaktadır: 320 piksel çözünürlükte, delik bölgesi stride-8 öznitelik haritasında yalnızca yaklaşık 1 hücreye (0,97) karşılık gelmektedir. Bu durum, öznitelik haritası düzeyinde nesnenin neredeyse tek bir noktaya indirgendiği, dolayısıyla kenar, doku ve şekil gibi ayırt edici özniteliklerin büyük ölçüde kaybolduğu kritik bir alt sınır (threshold) niteliğindedir. Bu bulgu, 320 piksel senaryosunda gözlemlenen belirgin biçimde düşük mAP50–95 (%70,9) ve recall (%83,9) değerleriyle doğrudan örtüşmektedir. 640 pikselde delik bölgesi yaklaşık 2 hücreye (1,94) karşılık gelmekte olup, bu değer modelin nesneyi komşu hücrelerle bağlamsal ilişki içinde değerlendirebilmesi için gerekli asgari eşiği aşan bir "gerçek zamanlı referans" noktası oluşturmaktadır; nitekim bu çözünürlükte performans metriklerinde belirgin bir sıçrama gözlemlenmiştir. 960 piksel, delik bölgesinin yaklaşık 3 hücreye (2,91) karşılık geldiği bir "denge adayı" konumundadır; performans kazanımı devam etmekle birlikte artık marjinal düzeydedir. 1280 pikselde delik bölgesi yaklaşık 4 hücreye (3,89) ulaşmakta ve bu çözünürlük, performansın doyum noktasına yaklaştığı, dolayısıyla yalnızca en yüksek hassasiyetin gerekli olduğu senaryolarda tercih edilebilecek bir "yüksek hassasiyet adayı" olarak nitelendirilebilir.

Bu geometrik analiz, Bölüm 5.1'de sunulan performans eğrisinin altında yatan nedensel mekanizmayı açıklaması bakımından önem taşımaktadır: performans artışının 320'den 640'a geçişte keskin, 640'tan sonra ise giderek yavaşlayan bir eğilim göstermesi, doğrudan delik bölgesinin öznitelik haritasındaki hücre sayısının 1'den 2'ye çıkışının kritik bir eşik değeri aşması, sonraki artışların ise (2'den 3'e, 3'ten 4'e) göreli olarak daha küçük marjinal katkılar sağlamasıyla açıklanabilir.

5.3. Hesaplama Maliyeti ve Uygulanabilirlik Analizi

Model performansındaki iyileşmenin pratik değeri, yalnızca doğruluk kazanımı ile değil, bu kazanımın getirdiği hesaplama maliyetiyle birlikte değerlendirilmelidir. Tablo 3'teki verilere dayanarak her çözünürlük seviyesi için bir "maliyet-fayda" değerlendirmesi yapıldığında, 320 pikselden 640 piksele geçişin mAP50–95'te 18,3 puanlık bir kazanım sağlarken gecikmede yalnızca 5,7 ms'lik (%7'lik) bir artışa yol açtığı görülmektedir; bu oran, söz konusu geçişi açık ara en verimli çözünürlük artışı hâline getirmektedir.

Buna karşılık 960'dan 1280 piksele geçiş, yalnızca 0,8 puanlık bir mAP50–95 kazanımı karşılığında gecikmede 11,6 ms'lik (%12'lik) bir artışa, VRAM kullanımında ise %50'lik bir yükselişe neden olmaktadır; bu da söz konusu geçişin maliyet-fayda açısından oldukça düşük verimli olduğunu göstermektedir.

FPS değerleri üzerinden değerlendirildiğinde, 320 piksel senaryosu 12,48 FPS ile en yüksek işlem hızını sunarken, 1280 piksel senaryosu 9,15 FPS ile en düşük hızı sunmaktadır. Her iki değer de tipik bir üretim hattı kamerasının saniyedeki görüntü işleme gereksinimini karşılayabilecek düzeydedir; dolayısıyla bu çalışmanın uygulama senaryosunda gecikme farkının gerçek zamanlı çalışabilirliği tehlikeye atmadığı, ancak çok istasyonlu veya yüksek üretim hızına sahip hatlarda bu farkın kümülatif olarak önemli hâle gelebileceği değerlendirilmektedir. VRAM kullanımındaki artış (0,08 GB'den 0,21 GB'ye), mutlak değerler açısından küçük görünse de, birden fazla modelin aynı anda çalıştırıldığı çok kameralı/çok istasyonlu endüstriyel sistemlerde donanım planlaması açısından dikkate alınması gereken bir husustur.

5.4. Bulguların Genel Değerlendirmesi

Elde edilen bulgular bir bütün olarak değerlendirildiğinde, giriş görüntü çözünürlüğünün küçük nesne tespiti performansı üzerinde belirleyici bir etkiye sahip olduğu, ancak bu etkinin doğrusal değil azalan getiriler eğrisine uygun bir örüntü izlediği görülmektedir. 320 piksel çözünürlük, hem genel performans metrikleri hem de gerçek nesne geometrisi analizi açısından kritik bir alt sınır (kritik alt sınır) olarak nitelendirilebilir; bu çözünürlükte hedef nesnenin öznitelik haritasındaki temsili yetersiz kalmakta ve model performansı belirgin biçimde düşmektedir. 640 piksel, performans-maliyet dengesi açısından en verimli "gerçek zamanlı referans" noktası olarak öne çıkmakta; düşük çözünürlüğe kıyasla önemli bir doğruluk kazanımı sağlarken, hesaplama maliyetindeki artış sınırlı kalmaktadır. 960 piksel, performansın doyum noktasına yaklaştığı ancak henüz maliyetin aşırı yükselmediği bir "denge adayı" konumundadır. 1280 piksel ise en yüksek doğruluğu sunmakla birlikte, marjinal kazanımın giderek küçüldüğü ve hesaplama maliyetinin belirgin biçimde arttığı bir "yüksek hassasiyet adayı" olarak, yalnızca doğruluğun her koşulda önceliklendirildiği uygulamalarda tercih edilmelidir.

6. SONUÇ VE ÖNERİLER

Bu çalışmada, derin öğrenme tabanlı küçük nesne tespitinde açık bir problem olarak kabul edilen çözünürlük-performans ilişkisi, Helicoil kalite kontrolü uygulaması üzerinden, kontrollü ve tekrarlanabilir bir deney tasarımı çerçevesinde sistematik olarak incelenmiştir. Aynı veri seti, aynı model mimarisi ve aynı hiperparametre konfigürasyonu altında yalnızca giriş çözünürlüğü (320, 640, 960, 1280 piksel) değiştirilerek gerçekleştirilen deneyler, çözünürlük artışının tespit doğruluğunu (mAP50–95: %70,9 → %92,1; recall: %83,9 → %96,8) belirgin biçimde iyileştirdiğini, ancak bu iyileşmenin eğitim süresi, çıkarım gecikmesi ve GPU bellek kullanımındaki artışlar biçiminde önemli bir hesaplama maliyeti karşılığında elde edildiğini göstermiştir.

Çalışmanın en önemli bulgusu, çözünürlük-performans ilişkisinin doğrusal olmadığı, aksine 320'den 640 piksele geçişte keskin bir iyileşme gösterirken 640 pikselden sonra azalan getiriler prensibine uygun biçimde doyuma ulaştığıdır. Bu örüntü, gerçek nesne geometrisi üzerinden yapılan analizle de desteklenmiş; hedef nesnenin (delik/Helicoil bölgesi) 320 piksel çözünürlükte öznitelik haritasında yalnızca yaklaşık 1 hücreye karşılık gelmesinin, bu çözünürlüğü kritik bir alt sınır hâline getirdiği; 640 piksel ve üzerinde ise nesnenin en az 2 hücrelik bir bağlamsal temsile kavuştuğu ve bunun performans sıçramasının altında yatan geometrik nedeni oluşturduğu ortaya konulmuştur.

Elde edilen bulgular ışığında, farklı uygulama senaryoları için aşağıdaki somut öneriler geliştirilmiştir:

- Gerçek zamanlı ve düşük gecikmeli sistemler için (örn. yüksek hızlı üretim hatları, çok istasyonlu eş zamanlı denetim): 640 piksel çözünürlük önerilmektedir. Bu seviye, 320 piksele kıyasla belirgin bir doğruluk kazanımı sağlarken, 960 ve 1280 piksele kıyasla önemli ölçüde daha düşük hesaplama maliyeti sunmaktadır.
- Yüksek hassasiyet gerektiren kritik kalite kontrol uygulamaları için (örn. güvenlik kritik parçalar, sıfır hata toleransı gereken hatlar): 960 veya 1280 piksel çözünürlük önerilmektedir. Bu seviyelerde elde edilen ilave doğruluk kazanımı, artan hesaplama maliyetine rağmen, hatalı parçanın gözden kaçırılması riskinin doğurabileceği maliyetten (yeniden işleme, garanti, itibar kaybı) daha düşük kalabilmektedir.

- Kaynak kısıtlı gömülü sistemler veya kenar (edge) cihazlarda çalıştırılacak uygulamalar için: 320 piksel çözünürlük, yalnızca hedef nesnenin göreli boyutunun veri setindekinden daha büyük olduğu veya ek mimari iyileştirmelerin (örneğin ek tespit katmanı, öznitelik piramidi güçlendirmesi) uygulandığı durumlarda değerlendirilmelidir; aksi hâlde bu çözünürlük küçük nesne tespiti için önerilmemektedir.
- Orta ölçekli, dengeli uygulamalar için: 960 piksel, doğruluk ve maliyet arasında en iyi dengeyi sunan nokta olarak değerlendirilebilir; özellikle 1280 piksele kıyasla anlamlı bir maliyet tasarrufu sağlarken performans kaybı sınırlı kalmaktadır.

Bu çalışmanın bazı sınırlılıkları bulunmaktadır. Öncelikle, deneyler tek bir model mimarisi (YOLO ailesi) ve tek bir uygulama alanı (Helicoil kalite kontrolü) üzerinde gerçekleştirilmiştir; bulguların farklı mimariler ve farklı nesne boyut dağılımlarına sahip veri setleri için genellenebilirliği ayrı bir doğrulama gerektirmektedir. İkinci olarak, çalışmada dört ayrık çözünürlük seviyesi (320, 640, 960, 1280) test edilmiş olup bu seviyeler arasındaki ara noktalarda (örneğin 480 veya 800 piksel) performans-maliyet eğrisinin tam şekli bilinmemektedir; gelecek çalışmalarda daha ince taneli (granüler) bir tarama ile doyum noktasının daha kesin biçimde belirlenmesi mümkün olacaktır. Son olarak, bu çalışma sabit bir çözünürlük yaklaşımını ele almış olup; çok ölçekli eğitim (multi-scale training), dinamik çözünürlük seçimi veya girdi görüntüsünün yalnızca ilgi alanı (region of interest) kısımlarının yüksek çözünürlükte işlendiği hibrit yaklaşımlar gibi alternatif stratejilerin, hem doğruluk hem de hesaplama verimliliği açısından daha da iyi sonuçlar sunup sunmayacağının gelecek çalışmalarda araştırılması önerilmektedir. Sonuç olarak, bu çalışma, giriş görüntü çözünürlüğünün derin öğrenme tabanlı küçük nesne tespiti performansı üzerindeki etkisini, kontrollü bir deney tasarımı ve gerçek nesne geometrisine dayalı nicel bir analizle birlikte ele alarak; hem akademik literatüre çözünürlük-performans ilişkisinin doğrusal olmayan doğasına dair somut kanıt sunmakta hem de endüstriyel uygulayıcılara model tasarımı sürecinde bilinçli ve gerekçelendirilmiş bir çözünürlük (ingsize) seçimi yapabilmeleri için pratik bir referans noktası sağlamaktadır.

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YÜKSEK HACİMLİ BATARYA PAKETLERİNDE KULLANILAN BTMS ÜNİTESİNİN BELİRLİ GÜÇ (KW) DEĞERLERİNDE TERMAL PERFORMANSININ DENEYSEL OLARAK İNCELENMESİ

EXPERIMENTAL INVESTIGATION OF THERMAL PERFORMANCE OF BTMS UNITS IN HIGH-VOLUME BATTERY PACKS AT SPECIFIC POWER (KW) LEVELS

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ÖZET

Elektrikli araçlar, enerji depolama istasyonları ve yüksek güçlü endüstriyel uygulamalarda yaygın olarak kullanılan lityum-iyon batarya paketlerinin güvenli, kararlı ve uzun ömürlü bir şekilde çalışabilmesi, büyük ölçüde etkin bir batarya termal yönetim sistemi (Battery Thermal Management System - BTMS) tarafından sağlanan sıcaklık kontrolüne bağlıdır. Batarya hücreleri, özellikle yüksek şarj ve deşarj güçlerinde elektrokimyasal reaksiyonlar ve iç direnç kaynaklı ısıl kayıplar nedeniyle önemli miktarda ısı üretmektedir. Bu ısının etkin bir biçimde uzaklaştırılamaması durumunda, hücreler arasında sıcaklık dengesizlikleri (thermal gradient), kapasite kaybı, çevrim ömründe azalma ve en kritik durumda termal kaçak (thermal runaway) gibi güvenlik riskleri ortaya çıkabilmektedir. Bu nedenle, yüksek hacimli batarya paketlerinde kullanılan BTMS ünitelerinin gerçek yük koşulları altında test edilerek performanslarının deneysel olarak doğrulanması, hem güvenlik hem de sistem verimliliği açısından büyük önem taşımaktadır.

Bu çalışmada, yüksek hacimli bir batarya paketi için tasarlanmış BTMS ünitesinin, belirlenen bir güç (kW) değerinde çalıştırılması durumunda batarya sıcaklığını hangi aralığa çektiği ve bu aralığı ne kadar sürede stabilize ettiği deneysel bir test düzeneği üzerinde incelenmiştir. Test sürecinde, batarya modülüne belirlenen sabit güç değeri altında yük uygulanmış ve BTMS ünitesi eş zamanlı olarak devreye alınarak sistemin soğutma performansı gözlemlenmiştir. BTMS üzerinde farklı noktalara yerleştirilen sıcaklık sensörleri aracılığıyla, test süresi boyunca belirli zaman aralıklarında sıcaklık verileri kaydedilmiştir. Bu sayede yalnızca sistemin ulaştığı nihai sıcaklık aralığı değil, aynı zamanda sıcaklığın zaman içerisindeki değişim eğrisi, soğuma hızı ve modül içi sıcaklık homojenliği gibi dinamik performans göstergeleri de değerlendirilmiştir.Elde edilen deneysel veriler, test edilen BTMS ünitesinin belirlenen güç değerinde çalıştırıldığında batarya sıcaklığını, lityum-iyon hücreler için literatürde genel kabul gören güvenli çalışma aralığına (yaklaşık 20-30°C bandı) çekebildiğini ve bu aralığı belirli bir süre içerisinde stabil şekilde koruyabildiğini ortaya koymuştur. Ayrıca BTMS içerisindeki farklı ölçüm noktaları arasındaki sıcaklık farkının kabul edilebilir sınırlar içerisinde kaldığı, bunun da hücreler arası dengesiz yaşlanmayı önlemek açısından olumlu bir gösterge olduğu değerlendirilmiştir. Çalışma sonucunda elde edilen bulgular, test edilen BTMS ünitesinin yüksek hacimli batarya paketlerinde belirtilen güç seviyesinde etkin bir termal kontrol sağladığını deneysel olarak ortaya koymaktadır.

Anahtar Kelimeler: Batarya Termal Yönetim Sistemi (BTMS), Lityum-İyon Batarya, Termal Test, Sıcaklık Kontrolü, Yüksek Kapasiteli Batarya, Termal Kaçak, Soğutma Performansı, Sıcaklık Homojenliği

ABSTRACT

Lithium-ion battery packs, widely used in electric vehicles, energy storage stations, and high-power industrial applications, require safe, stable, and long-lasting operation. This is largely dependent on effective temperature control provided by a Battery Thermal Management System (BTMS). At high charge and discharge power levels, battery cells generate significant heat due to electrochemical reactions and internal resistance losses. If this heat is not effectively dissipated, risks such as temperature imbalances between cells (thermal gradient), capacity loss, reduced cycle life, and, in the most critical case, thermal runaway can occur. Therefore, experimentally validating the performance of BTMS units under real load conditions in high-volume battery packs is crucial for both safety and system efficiency. In this study, the BTMS unit designed for a high-volume battery pack was experimentally tested to determine the temperature range achieved when operated at a specified power (kW) level, and the time required to stabilize within that range.

During the test, a constant load was applied to the battery module, while the BTMS unit was simultaneously activated to observe cooling performance. Temperature sensors placed at different points on the BTMS recorded data at regular intervals throughout the test. This allowed evaluation not only of the final stabilized temperature range but also of dynamic performance indicators such as temperature variation over time, cooling rate, and intra-module temperature uniformity.

The experimental results demonstrated that the tested BTMS unit successfully reduced the battery temperature to the generally accepted safe operating range for lithium-ion cells (approximately 20–30°C) and maintained stability within this range over time. Furthermore, the temperature differences between measurement points remained within acceptable limits, indicating effective prevention of uneven cell aging. Overall, the findings confirm that the tested BTMS unit provides efficient thermal control for high-volume battery packs at the specified power level.

Keywords: Battery Thermal Management System (BTMS), Lithium-Ion Battery, Thermal Testing, Temperature Control, High-Capacity Battery, Thermal Runaway, Cooling Performance, Temperature Uniformity

1. GİRİŞ VE KURAMSAL ÇERÇEVE

1.1. Lityum-İyon Bataryalarda Isıl Davranış ve Güvenlik Riskleri

Lityum-iyon bataryalar, sahip oldukları yüksek enerji ve güç yoğunluğu, düşük kendi kendine deşarj oranı ve uzun çevrim ömrü nedeniyle elektrikli araçlardan sabit enerji depolama sistemlerine kadar geniş bir uygulama yelpazesinde tercih edilmektedir. Ancak bu avantajların sürdürülebilir biçimde korunabilmesi, hücre sıcaklığının belirli bir aralıkta tutulmasına sıkı sıkıya bağlıdır. Şarj ve deşarj sırasında hücre içerisinde iç direnç kaynaklı Joule ısınması (I^2R kayıpları) ile elektrot/elektrolit arayüzeyindeki tersinir ve tersinmez elektrokimyasal reaksiyonlardan kaynaklanan ısı üretimi meydana gelmektedir. Özellikle yüksek C-oranlarında (hızlı şarj/deşarj) çalışan yüksek hacimli paketlerde bu ısı üretim hızı, pasif ısı yayılım kapasitesinin çok üzerine çıkabilmekte ve hücre sıcaklığının hızla yükselmesine neden olabilmektedir.

Hücre sıcaklığının önerilen aralığın dışına çıkması, kısa vadede performans kaybına (iç direncin artması, kapasitenin gerilim altında düşmesi), orta vadede kalıcı kapasite kaybına ve çevrim ömrünün kısalmasına, uzun vadede ise güvenlik açısından kritik sonuçlara yol açabilmektedir. Düşük sıcaklıklarda lityum plaklaşması (lithium plating) riski artarken, yüksek sıcaklıklarda katı elektrolit ara yüzeyinin (SEI) hızlanan büyümesi ve elektrolit ayrışması gibi istenmeyen yan reaksiyonlar hızlanmaktadır. En kritik senaryoda ise, iç kısa devre, mekanik hasar, elektriksel istismar (aşırı şarj/deşarj) veya harici ısıl istismar gibi tetikleyicilerin oluşturduğu zincirleme ekzotermik reaksiyonlar, hücre sıcaklığının kontrolsüz biçimde yükselmesine, yani termal kaçağa (thermal runaway) yol açabilmektedir [1]. Termal kaçak sürecinde salınan gazlar ve ani basınç artışı, komşu hücrelere yayılan (propagasyon) bir zincirleme reaksiyona dönüşerek yangın ve patlama riskini beraberinde getirmektedir; bu nedenle termal kaçağın erken tetikleyicilerinin önlenmesi ve mekanizmalarının anlaşılması, batarya paketi güvenlik mühendisliğinin merkezi konularından biri olarak öne çıkmaktadır [2]. Bu çerçevede, hücre sıcaklığını sürekli olarak güvenli bir bantta tutan bir BTMS ünitesi, yalnızca performans değil aynı zamanda birincil bir güvenlik bileşeni olarak değerlendirilmelidir.

1.2. Hücreler Arası Sıcaklık Dengesizliğinin Yaşlanmaya Etkisi

Yüksek hacimli batarya paketlerinde tek bir hücrenin ortalama sıcaklığı kadar, paket içerisindeki farklı hücreler veya farklı ölçüm noktaları arasındaki sıcaklık farkı (ΔT) da kritik bir performans göstergesidir. Paralel bağlı hücrelerde sıcaklık farkı, hücreler arasında akım paylaşımının dengesiz olmasına yol açmakta; sıcak hücre daha fazla akım çekerek daha hızlı yaşlanmakta, bu durum zamanla paket kapasitesinin sıcaklık farkı ile yaklaşık doğrusal biçimde azalmasına neden olmaktadır [3]. Seri bağlı konfigürasyonlarda ise sıcaklık dengesizliği, hücreler arası gerilim sapmasını büyüterek bazı hücrelerin erken aşırı şarj/deşarj koruma eşiğine ulaşmasına ve dolayısıyla paketin kullanılabilir kapasitesinin en zayıf hücre tarafından sınırlanmasına yol açmaktadır. Bu nedenle bir BTMS ünitesinin başarısı yalnızca ulaştığı mutlak sıcaklık seviyesiyle değil, aynı zamanda modül içerisindeki farklı ölçüm noktaları arasındaki sıcaklık homojenliğiyle de değerlendirilmelidir; bu çalışmada da giriş ve çıkış sıcaklıkları arasındaki fark bu amaçla ayrıca incelenmiştir.

1.3. Batarya Termal Yönetim Sistemi (BTMS) Teknolojileri

Literatürde batarya termal yönetimi için başlıca dört yaklaşım öne çıkmaktadır: hava soğutmalı sistemler, faz değiştiren malzeme (PCM) tabanlı pasif sistemler, sıvı soğutma plakası (cold plate) tabanlı sistemler ve soğutkan gaz akışkanlı (buhar sıkıştırmalı) aktif soğutma sistemleridir. Hava soğutmalı sistemler basit ve düşük maliyetli olmakla birlikte, havanın düşük ısı taşıma katsayısı nedeniyle yüksek güç yoğunluklu paketlerde yetersiz kalmaktadır. PCM tabanlı sistemler, faz değişimi sırasında gizli ısıyı absorbe ederek sıcaklık dalgalanmalarını pasif biçimde sönümler; ancak PCM'in tek başına ısıyı sürekli olarak ortamdan uzaklaştıramaması, uzun süreli yüksek yükte doygunluğa ulaşmasına neden olmaktadır; bu nedenle PCM genellikle sıvı soğutma ile hibrit biçimde kullanılmaktadır [4]. Sıvı soğutma plakası (LCP) tabanlı sistemler, akışkanın yüksek ısı taşıma kapasitesi sayesinde sıcaklık homojenliğini iyileştirmekte ve hızlı şarj koşullarını destekleyebilmektedir; yapısal tasarım, kanal geometrisi, akışkan tipi ve sistem mimarisi bu teknolojinin performansını belirleyen temel parametreler olarak öne çıkmaktadır [5].

Bu çalışmada incelenen BTMS ünitesi ise, yüksek hacimli paketlerin ihtiyaç duyduğu yüksek ısı akısı kapasitesini sağlayabilmek amacıyla, buhar sıkıştırmalı bir soğutkan gaz çevrimi (kompresör–kondenser–eşanjör) ile dolaylı sıvı soğutma hattını (pompa–soğutma plakası/batarya) bir araya getiren aktif-hibrit bir mimari kullanmaktadır. Bu yaklaşımda soğutkan gaz çevrimi, sıvı hattındaki soğutucu akışkanı bir eşanjör (chiller) üzerinden aktif olarak soğutmakta, soğutulan akışkan ise doğrudan batarya paketi üzerindeki soğutma plakasına dolaştırılmaktadır. Bu mimari, yalnızca pasif ortam havasına bağımlı kalmadan, ortam sıcaklığından bağımsız olarak hedef sıcaklığın altına inebilme (aktif soğutma) esnekliği sunması nedeniyle yüksek güçte çalışan büyük hacimli paketler için tercih edilmektedir.

1.4. Kapalı Çevrim Sıcaklık Kontrolü ve PID Yaklaşımı

Soğutkan gaz tabanlı bir BTMS ünitesinde soğutma kapasitesi, esas olarak kompresörün devir hızı (dolayısıyla akışkan debisi ve basınç oranı) değiştirilerek ayarlanır. Sabit devirli (on/off) bir kompresör, hedef sıcaklık etrafında büyük genlikli salınımlara ve gereğinden fazla enerji tüketimine yol açabileceğinden, yüksek performanslı BTMS ünitelerinde kompresör devri kapalı çevrim bir geri beslemeli kontrolcü ile sürekli olarak modüle edilir. Bu amaçla en yaygın kullanılan yöntem, sanayi otomasyonunda ve iklimlendirme/soğutma sistemlerinde onlarca yıldır kanıtlanmış biçimde uygulanan oransal-integral-türev (Proportional-Integral-Derivative, PID) kontrol algoritmasıdır [6]. PID kontrolcü, ölçülen çıkış (bu çalışmada batarya çıkış sıcaklığı) ile hedef set değeri arasındaki anlık hatayı sürekli hesaplayarak, bu hatanın büyüklüğüne, birikimine ve değişim hızına duyarlı bir kontrol sinyali üretir; bu sinyal kompresörün devir komutuna dönüştürülerek soğutma kapasitesi dinamik biçimde ayarlanır. Bu çalışmanın yöntem bölümünde, test edilen ünitenin PID kontrol mimarisi, kontrol denklemi ve her bir terimin (P, I, D) sistem davranışına etkisi ayrıntılı biçimde ele alınmaktadır.

2. ÇALIŞMANIN AMACI VE KAPSAMI

Bu çalışmanın temel amacı, yüksek hacimli bir batarya paketine entegre edilmiş, soğutkan gaz tabanlı ve PID kontrollü aktif bir BTMS ünitesinin, belirli bir güç (kW) seviyesinde çalıştırılması durumunda sergilediği termal performansı deneysel olarak ortaya koymaktır. Bu genel amaç doğrultusunda çalışma kapsamında aşağıdaki sorulara yanıt aranmıştır:

- BTMS ünitesi, 3,6 kW sabit güç yükü altında batarya sıcaklığını hangi aralığa çekmektedir ve bu aralık literatürde kabul gören güvenli çalışma bandı (yaklaşık 20-30°C) ile ne ölçüde örtüşmektedir?
- Sistem, hedef sıcaklık bandına ne kadar sürede ulaşmakta ve bu bandı ne kadar süre boyunca kararlı biçimde koruyabilmektedir?
- Kompresör devri, fan devri, yüksek basınç ve akım/gerilim gibi parametrelerin zaman içindeki değişimi, PID kontrol mimarisinin beklenen davranışıyla (hızlı geçici rejim + kararlı modülasyon) ne ölçüde uyumludur?
- BTMS içerisindeki farklı ölçüm noktaları (giriş/çıkış) arasındaki sıcaklık farkı, hücreler arası dengesiz yaşlanma riski açısından kabul edilebilir sınırlar içerisinde midir?

Çalışmanın kapsamı, soğutkan gaz çevrimli ve PID kontrollü tek bir BTMS ünitesinin 3,6 kW sabit elektriksel yük senaryosunda gerçekleştirilen deneysel test koşuluyla sınırlıdır.

Çalışma; ünitenin mekanik/hidrolik bileşenlerinin tanıtımı, sistemin akış şeması üzerinden çalışma prensibinin açıklanması, kompresör devrini yöneten kapalı çevrim PID kontrol mimarisinin detaylı biçimde ortaya konması ve son olarak test sırasında toplanan zaman serisi verilerinin (sıcaklık, basınç, devir, akım/gerilim) yorumlanmasını içermektedir. Farklı güç seviyeleri, farklı ortam sıcaklıkları veya uzun dönemli yaşlanma testleri bu çalışmanın kapsamı dışında bırakılmış, gelecek çalışmalar için öneri olarak sunulmuştur.

3. MATERYAL VE YÖNTEM

3.1. Test Edilen BTMS Ünitesi ve Sistem Tanıtımı

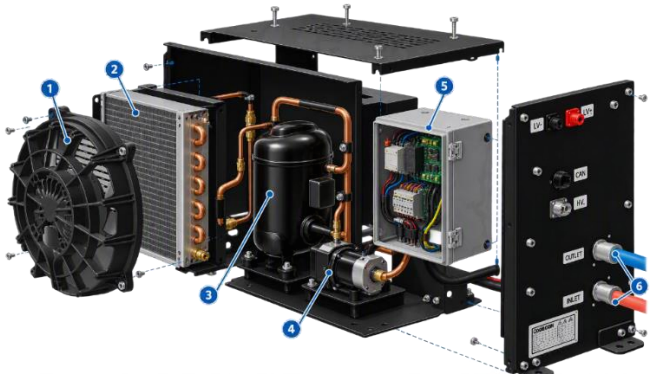
Çalışmada kullanılan BTMS ünitesi, soğutkan gaz tabanlı aktif bir soğutma modülüdür. Ünite; düşük gerilim (LV+/LV-), yüksek gerilim (HV) ve CAN haberleşme bağlantı noktaları ile sıvı giriş (INLET) ve sıvı çıkış (OUTLET) portlarına sahip, batarya paketinin üzerine veya yanına monte edilebilecek kompakt bir kabin içerisinde tasarlanmıştır. Ünitenin ürettiği soğutulmuş akışkan, batarya modülünün içerisine yerleştirilmiş, birbirini takip eden (serpantin tipi) kanallara sahip bir soğutma plakası (cold plate) üzerinden dolaştırılarak hücrelerle dolaylı ısı alışverişi sağlanmaktadır. Şekil 1'de, test edilen BTMS ünitesinin batarya paketine entegrasyonu ve soğutma plakası üzerindeki akışkan güzergâhı (mavi: besleme/soğuk hat, kırmızı: dönüş/ısınmış hat) şematik olarak gösterilmektedir.



Şekil 1. BTMS ünitesinin batarya paketine entegrasyonu ve soğutma plakası akışkan güzergâhı.

3.2. BTMS Ünitesinin Yapısal Bileşenleri

BTMS ünitesi, mekanik gövde, ısı eşanjörleri, akışkan devresi elemanları ve elektronik kontrol donanımını bir araya getiren çok bileşenli bir sistemdir. Şekil 2'de ünitenin patlatılmış (exploded) görünümü ve numaralandırılmış bileşenleri sunulmaktadır. Aşağıda her bir bileşen, işlevi ve mühendislik açısından önemi ile birlikte ayrıntılı biçimde açıklanmaktadır.



Şekil 2. BTMS ünitesinin patlatılmış (exploded) görünümü

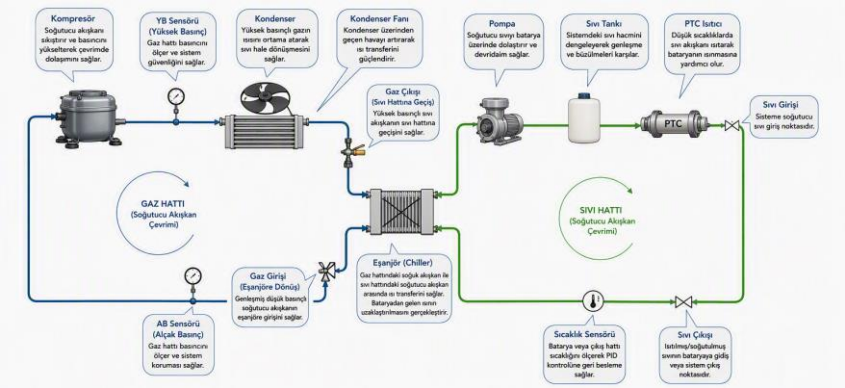
No	Bileşen	İşlevi
1	**Fan**	Kondenser üzerinden geçen havayı zorlanmış taşınım (forced convection) ile hızlandırarak soğutkan gazın atmosfere ısı aktarımını güçlendirir; devri sabit veya kademeli olarak çalışabilir.
2	**Kondenser**	Kompresörden çıkan yüksek basınçlı ve yüksek sıcaklıklı soğutkan gazının, hava ile ısı alışverişi yaparak yoğuşmasını (gaz-sıvı faz değişimini) sağlayan hava soğutmalı eşanjördür.
3	**Kompresör**	Kompresör, soğutkan gazı sıkıştırarak çevrim boyunca dolaşımını sağlayan ve soğutma kapasitesini PID komutuyla ayarlanan devriyle belirleyen ana tahrik elemanıdır; akümülatör ise kompresöre sıvı halde soğutkan gaz gitmesini (sıvı darbesi) önleyerek kompresörü korur ve sistemdeki fazla soğutkan gazı depolar.
4	**Pompa**	Pompa, soğutma sıvısını batarya ile ısı değiştirici arasında dolaştırarak batarya hücrelerinden alınan ısının sistemden uzaklaştırılmasını sağlar. Böylece batarya sıcaklığının dengeli ve güvenli çalışma aralığında tutulmasına yardımcı olur.
5	**Elektrik / Kontrol Kutusu**	PID kontrolcüyü, güç elektroniği kartlarını, sensör arayüzlerini ve CAN haberleşme donanımını barındıran; sistemin "beyni" konumundaki bölmedir.
6	**Sıvı Giriş / Çıkışı**	BTMS ünitesi ile batarya paketindeki soğutma plakası arasındaki sıvı hattını birbirine bağlayan giriş ve çıkış bağlantı noktalarıdır.

Tablo 1. BTMS ünitesinin yapısal bileşenleri ve işlevleri.

Bileşenlerin birlikte oluşturduğu mekanik yapı incelendiğinde, sol tarafta hava tahliyesini sağlayan fan ve koruyucu kapak, hemen yanında ısı reddi (heat rejection) işlevini üstlenen kondenser, onun yanında soğutma kapasitesini üreten kompresör-akümülatör grubu ile elektrik/kontrol kutusu, altta ise sıvı sirkülasyonunun kaynağı pompa elemanı yer almaktadır. Bu katmanlı yerleşim, hem servis edilebilirliği kolaylaştırmakta hem de sıcak (kondenser/kompresör) ve soğuk (sıvı hattı) bölgeler arasındaki istenmeyen ısı geçişini sınırlamaktadır.

3.3. Soğutucu Akışkan Devresi ve Sistem Akış Şeması

BTMS ünitesinin iç mimarisi, birbirinden ayrı fakat bir eşanjör (chiller) üzerinden termal olarak eşleşen iki devreden oluşmaktadır: (i) soğutkan gaz akışkanının dolaştığı gaz hattı ve (ii) batarya paketine giden soğutucu sıvının dolaştığı sıvı hattı. Şekil 3'te bu iki devrenin tüm bileşenleri, sensörleri ve kontrol vanalarıyla birlikte tam akış şeması sunulmaktadır.



Şekil 3. BTMS ünitesinin gaz hattı (soğutkan gaz çevrimi) ve sıvı hattı (soğutucu akışkan çevrimi) sistem akış şeması.

3.3.1. Gaz Hattı (Soğutkan Gaz Akışkan Çevrimi)

Soğutkan gaz çevrimi klasik buhar sıkıştırmalı soğutma çevrimine dayanmaktadır. Kompresör, düşük basınçlı soğutkan gazını sıkıştırarak basıncını ve sıcaklığını yükseltir ve çevrim boyunca akışkanın dolaşımını sağlar. Kompresör çıkışındaki yüksek basınç, YB (Yüksek Basınç) sensörü ile sürekli izlenerek hem PID kontrol döngüsüne veri sağlanır hem de sistem güvenliği (aşırı basınç koruması) gözetilir. Sıkıştırılan sıcak gaz, kondenserden geçerek kondenser fanının desteğiyle ortam havasına ısısını bırakır ve yoğuşarak yüksek basınçlı sıvı hâline dönüşür (Gaz Çıkışı – Sıvı Hattına Geçiş). Bu yüksek basınçlı sıvı, bir genleşme/kontrol vanasından geçirilerek eşanjöre (chiller) yönlendirilir. Eşanjörde, gaz hattındaki düşük basınç ve düşük sıcaklıktaki soğutkan gaz, sıvı hattındaki soğutucu akışkanla ısı alışverişine girerek batarya tarafından gelen ısıyı üzerine alır ve buharlaşır. Genleşmiş, düşük basınçlı soğutkan gazı, AB (Alçak Basınç) sensöründen geçerek (Gaz Girişi – Eşanjöre Dönüş) tekrar kompresöre döner ve çevrim baştan tamamlanır. Özetle gaz hattındaki akış sırası:
Kompresör → Kondenser → Eşanjör (ısı transferi) → Kompresör
şeklindedir.

3.3.2. Sıvı Hattı (Soğutucu Akışkan Çevrimi)

Sıvı hattı, batarya paketi ile eşanjör arasında ısı taşınımını sağlayan dolaylı soğutma devresidir. Batarya paketinden çıkan ısınmış soğutucu akışkan (Sıvı Çıkışı), hattaki bir sıcaklık sensöründen geçerek ölçülür; bu ölçüm hem izleme hem de PID kontrol döngüsüne geri besleme sağlamak amacıyla kullanılır. Ardından akışkan, bir pompa yardımıyla devrede dolaştırılarak eşanjöre iletilir. Eşanjörde akışkan, soğutkan gaz tarafına ısısını vererek soğur; soğuyan akışkan bir sıvı tankına (genleşme/dengeleme tankı) uğrayarak sistemdeki hacimsel genleşme ve büzülmeler dengelenir. Gerekmesi hâlinde (örneğin düşük ortam sıcaklıklarında) akışkan bir PTC (Positive Temperature Coefficient) ısıtıcıdan geçirilebilir; aksi hâlde PTC hattı by-pass edilir. Son olarak soğutulmuş akışkan, Sıvı Girişi noktasından tekrar batarya paketine gönderilir. Özetle soğutma çevrimindeki akış sırası:
Batarya → Sıvı Çıkışı → Sıcaklık Sensörü → Pompa → Eşanjör (ısı transferi) → Sıvı Tankı → PTC (gerekirse by-pass) → Sıvı Girişi → Batarya
şeklindedir.

3.3.3. Isıtma Çevrimi (PTC Isıtıcı ile)

Düşük ortam sıcaklıklarında lityum plaklaşması riskini önlemek ve bataryanın verimli çalışabileceği minimum sıcaklığa ulaşmasını hızlandırmak amacıyla sistem, bir PTC ısıtıcı üzerinden ısıtma moduna geçebilmektedir. Bu modda akış sırası:
Sıvı Girişi → PTC Isıtıcı → Sıvı Tankı → Pompa → Batarya → Sıcaklık Sensörü → Sıvı Çıkışı
şeklinde gerçekleşmekte, soğutma çevrimi ile aynı hidrolik devre farklı bir enerji kaynağıyla (PTC) kullanılmaktadır. Bu çift modlu (soğutma/ısıtma) yapı, BTMS ünitesinin yalnızca aşırı ısınmayı değil, aynı zamanda düşük sıcaklık kaynaklı performans kayıplarını da önleyecek biçimde tasarlandığını göstermektedir.

3.3.4. Kontrol Hedefi

Sistemin akış şemasında tanımlanan kontrol hedefi dört ana ilkeye dayanmaktadır: (i) batarya çıkış sıvısı sıcaklığını (T_out) set değerinde (T_set) tutmak, (ii) aşırı sıcaklıkları engellemek, (iii) sıcaklık dalgalanmasını minimize ederek kararlılık sağlamak ve (iv) enerji tüketimini optimize etmek. Bu dört ilke, aşağıda ayrıntılı biçimde açıklanan PID kontrol mimarisinin tasarım gerekçesini oluşturmaktadır.

3.4. PID Kontrol Mimarisi ve Kompresör Devir Denetimi

BTMS ünitesinin soğutma kapasitesi, kompresör devrinin sürekli olarak ayarlanmasıyla kontrol edilmektedir. Bu ayarlama, kapalı çevrim bir PID kontrol döngüsü tarafından gerçekleştirilmektedir. Şekil 4'te, sistemin kapalı çevrim PID kontrol blok diyagramı gösterilmektedir.



Şekil 4. Kapalı çevrim PID kontrol döngüsü blok diyagramı.

Blok diyagramda görüldüğü üzere, sıcaklık set değeri T_{set}(°C) ile ölçülen batarya çıkış sıcaklığı T_{out}(°C) arasındaki fark, hata sinyali e(t) olarak tanımlanmaktadır ($e(t) = T_{set} - T_{out}$). Bu hata sinyali PID denetleyiciye girdi olarak verilmekte; denetleyici, hatayı oransal, integral ve türev bileşenleriyle işleyerek 0–6000 rpm aralığında bir kompresör devir komutu üretmektedir. Bu komut, BTMS prosesine (termal sisteme) uygulanmakta ve sonucunda elde edilen batarya çıkış sıcaklığı, sıcaklık sensörü aracılığıyla tekrar geri beslenerek döngü kapatılmaktadır. PID denetleyicinin çıkışı klasik kontrol mühendisliğinde aşağıdaki biçimde ifade edilir:

$$u(t) = K_p.e(t) + K_i.\int_0^t e(\tau)d\tau + K_d.\frac{de(t)}{dt}$$

3.4.1. Oransal Terim (Kp) – Oransal Kontrol

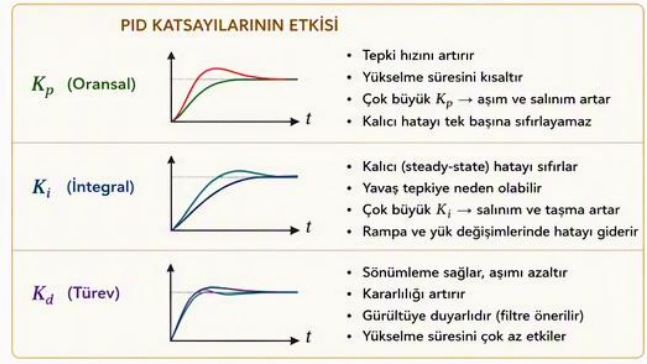
Oransal terim, kontrol sinyalini anlık hatanın büyüklüğüyle doğru orantılı biçimde üretir. Hata büyükse (örneğin test başlangıcında sıcaklık set değerinden çok uzaktaysa) kompresöre yüksek devir komutu verilerek hızlı bir tepki elde edilir; hata küçüldükçe komut da orantılı olarak azalır. Kp kazancının artırılması sistemin tepki hızını yükseltir ve yükselme süresini (rise time) kısaltır; bu çalışmada gözlemlenen ilk ~80 saniyelik hızlı kompresör devri artışı, oransal terimin baskın olduğu bu geçici rejim davranışının tipik bir göstergesidir. Ancak Kp'nin gereğinden büyük seçilmesi durumunda sistemde aşım (overshoot) ve salınım (oscillation) riski artar; ayrıca oransal terim tek başına kalıcı durum hatasını (steady-state error) sıfırlayamaz, yani sistem sürekli hâlde set değerinin biraz altında veya üstünde kalabilir. Bu eksiklik, integral terimi tarafından giderilmektedir.

3.4.2. İntegral Terim (Ki) – İntegral Kontrol

İntegral terim, geçmişten bugüne biriken hatanın toplamını (integralini) dikkate alarak kalıcı durum hatasını sıfırlamayı amaçlar. Oransal terim tek başına yetersiz kaldığında (örneğin sistem set değerine çok yaklaşmış ancak tam oturamamışken), integral terim küçük fakat sürekli bir hatayı zamanla biriktirerek kontrol sinyaline ek bir düzeltme uygular ve sistemin tam olarak set değerine oturmasını sağlar. İntegral terim ayrıca rampa tipi yük değişimlerinde (yükün kademeli olarak artması/azalması gibi) oluşan hataların giderilmesinde de etkilidir. Bununla birlikte, Ki kazancının büyük seçilmesi sistemde salınım ve taşmaya (aşırı tepkiye) yol açabilir; ayrıca kompresör devri fiziksel olarak 0–6000 rpm aralığıyla sınırlı olduğundan, hata uzun süre büyük kaldığında integral terimin sınırsız biçimde birikmesi "integral doygunluğu" (integral windup) adı verilen bir soruna yol açabilir. Bu nedenle pratik uygulamalarda, aktüatör (kompresör) doygunluğa ulaştığında integral birikimini durduran veya geri alan "anti-windup" mekanizmalarının kullanılması önerilmektedir; bu çalışmada gözlemlenen, kompresör devrinin belirli bir üst sınırda (~6000 rpm) düzleşerek plato yaptığı evre, aktüatör doygunluğunun pratikte nasıl ortaya çıktığına dair somut bir örnek teşkil etmektedir.

3.4.3. Türev Terim (Kd) – Türev Kontrol

Türev terim, hatanın değişim hızına (de/dt) duyarlı çalışarak bir tür "öngörülü" fren görevi görür. Sıcaklık hızla set değerine yaklaşırken (hata hızla azalırken), türev terimi kontrol sinyalini önceden azaltarak sistemin set değerini aşmasını (overshoot) engeller ve sönümleme (damping) sağlar; bu sayede sistemin kararlılığı ve oturma davranışı iyileşir. Türev teriminin en önemli dezavantajı, sensör gürültüsüne karşı yüksek duyarlılığıdır; ölçüm sinyalindeki küçük dalgalanmalar türev alma işlemiyle büyütülerek kontrol sinyaline gürültü olarak yansıyabilir, bu nedenle uygulamada türev teriminin bir alçak geçiren filtre ile yumuşatılması yaygın bir mühendislik pratiğidir. Türev kazancı ayrıca yükselme süresini de doğrudan etkilemektedir; çok yüksek Kd değerleri sistemi aşırı yavaşlatabilir.
Şekil 5'te, Kp, Ki ve Kd katsayılarının sistem tepkisi üzerindeki etkileri karşılaştırmalı olarak özetlenmektedir.



Şekil 5. PID katsayılarının (Kp, Ki, Kd) sistem tepkisi üzerindeki etkilerinin karşılaştırmalı özeti.

Test edilen BTMS ünitesinde, PID denetleyicinin çıktısı doğrudan kompresörün devir komutuna (0–6000 rpm aralığında) dönüştürülmektedir. BTMS'nin termal süreç olarak davranışı, önemli bir ısıl kütleye (soğutucu akışkan hacmi, eşanjör metali, batarya paketinin kendisi) sahip olması nedeniyle belirgin bir zaman gecikmesi (dead-time) ve birinci dereceden gecikme (lag) karakteristiği sergilemektedir; bu da PID kazançlarının, örneğin Ziegler–Nichols veya Cohen–Coon gibi klasik yöntemlerle veya otomatik ayarlama (auto-tuning) algoritmalarıyla dikkatli biçimde ayarlanmasını gerektirmektedir [6]. Test verilerinde gözlemlenen, kompresör devrinin belirli bir kararlı rejim evresinde 3500–6000 rpm aralığında tekrarlı biçimde salınım göstermesi, PID çıkışının kompresörün ayrık/adımlı çalışma kapasitesi (operating envelope) içerisinde sürekli olarak yeniden hesaplanmasının bir sonucu olarak yorumlanmaktadır; bu davranış, aşağıda Bulgular bölümünde ayrıntılı biçimde ele alınmaktadır. Fan devrinin test boyunca ~900 rpm civarında sabit kalması ise, bu çalışmada fan hızının kompresörden bağımsız, sabit veya basit kademeli bir mantıkla yönetildiğine işaret etmektedir.

3.5. Deney Düzeneği, Test Koşulları ve Veri Toplama Yöntemi

Deneysel çalışma, batarya modülüne 3,6 kW sabit elektriksel güç yükü uygulanarak gerçekleştirilmiştir. Yük, batarya modülünün gerçek operasyonel koşullarını (yüksek güçte şarj/deşarj) temsil edecek biçimde programlanabilir bir yük/kaynak ünitesi üzerinden sabit güçte uygulanmış; BTMS ünitesi bu yükle eş zamanlı olarak devreye alınarak soğutma performansı gerçek yük altında izlenmiştir. Test süresince aşağıdaki kanallar yüksek çözünürlüklü biçimde kaydedilmiştir:

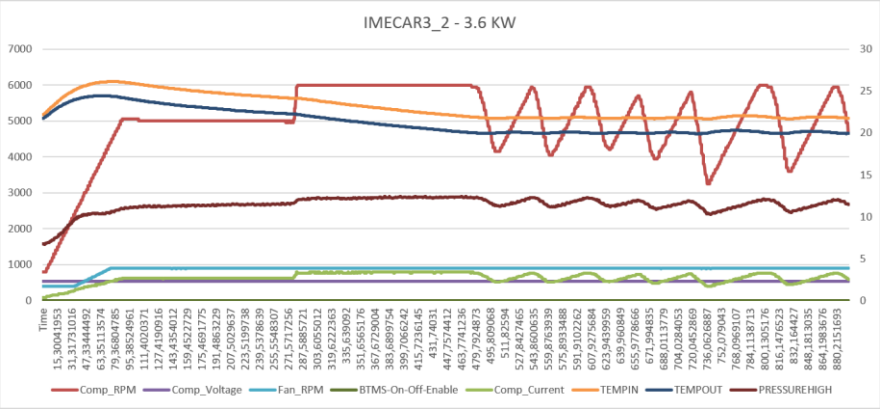
- TEMPIN (°C) – BTMS/soğutma plakası giriş sıvı sıcaklığı
- TEMPOUT (°C) – BTMS/soğutma plakası çıkış sıvı sıcaklığı (PID geri besleme sinyali)
- PRESSUREHIGH (bar) – Soğutkan gaz çevrimi yüksek basınç değeri
- Comp_RPM (rpm) – Kompresör devri (PID kontrol çıkışı, 0–6000 rpm)
- Comp_Current (A) ve Comp_Voltage (V) – Kompresör elektriksel çalışma parametreleri
- Fan_RPM (rpm) – Kondenser fanı devri
- BTMS-On-Off-Enable – Sistemin devrede olma/olmama durum sinyali

Test, toplam yaklaşık 880 saniye (~14,7 dakika) sürmüş ve bu süre boyunca sistem hem hızlı geçici rejim (transient) evresini hem de uzun süreli kararlı rejim (steady-state) modülasyon evresini kapsayacak biçimde izlenmiştir.

TEMPIN ve TEMPOUT sensörlerinin birlikte değerlendirilmesi, yalnızca sistemin ulaştığı nihai sıcaklık aralığının değil, aynı zamanda modül giriş-çıkışı arasındaki sıcaklık homojenliğinin de nicel biçimde değerlendirilmesine imkân tanımıştır.

4. BULGULAR

Şekil 6'da, 3,6 kW güç koşulunda gerçekleştirilen deneyde kaydedilen tüm kanalların (Comp_RPM, Comp_Voltage, Fan_RPM, BTMS-On-Off-Enable, Comp_Current, TEMPIN, TEMPOUT, PRESSUREHIGH) zamana bağlı değişimi sunulmaktadır. Bulgular, testin ayırt edici üç evresi (geçici rejim, yüksek kapasite platosu ve kararlı rejim modülasyonu) çerçevesinde aşağıda ayrıntılı biçimde yorumlanmıştır.



Şekil 6. BTMS'in 3,6 kW test koşulunda kaydedilen zaman serisi verileri

4.1. Geçici Rejim (Transient) Davranışı (t ≈ 0–270 s)

Test başlangıcında, 3,6 kW yükün uygulanmasıyla birlikte BTMS ünitesi devreye girmiş ve PID kontrolcünün oransal teriminin baskın olduğu hızlı bir tepki evresi gözlemlenmiştir. Kompresör devri (Comp_RPM), yaklaşık 800 rpm başlangıç değerinden yaklaşık 63-80 saniye içerisinde tepe değeri olan ~5000 rpm seviyesine hızla yükselmiştir; bu davranış, hata sinyalinin başlangıçta büyük olması nedeniyle oransal terimin maksimum kapasiteye yakın bir kontrol sinyali ürettiğini göstermektedir. Bu hızlı soğutma tepkisiyle eş zamanlı olarak TEMPIN değeri yaklaşık 26°C'den 21-22°C seviyelerine, TEMPOUT değeri ise yaklaşık 24-25°C'den 19-20°C seviyelerine gerilemiştir. Aynı evrede soğutkan gaz çevrimindeki yüksek basınç (PRESSUREHIGH), kompresör devrindeki artışla orantılı biçimde yükselerek yaklaşık 12-13 bar seviyelerine ulaşmıştır. Kondenser fan devri (Fan_RPM) de bu evrede hızla artarak ~900 rpm seviyesinde bir platoya oturmuş ve testin geri kalanında bu seviyede sabit kalmıştır.

4.2. Yüksek Kapasite Platosu (t ≈ 270-480 s)

Sıcaklık hedef bandına yaklaştıktan sonra, kompresör devri kısa bir süreliğine tekrar yükselerek yaklaşık 6000 rpm seviyesinde ikinci bir platoya oturmuş ve bu seviyeyi yaklaşık 480. saniyeye kadar korumuştur. Bu evre, sistemin biriken ısıl yükü (özellikle sıvı tankı ve soğutma plakasındaki ısıl atalet nedeniyle) tam olarak boşaltabilmek amacıyla soğutma kapasitesini bir süre daha yüksek tuttuğu bir ara evre olarak yorumlanabilir. Bu evrede TEMPIN ve TEMPOUT değerleri kademeli olarak düşüşünü sürdürmüş ve hedef banda daha da yaklaşmıştır.

4.3. Kararlı Rejim (Steady-State) PID Modülasyonu (t ≈ 480-880 s)

Set sıcaklığına ulaşıldıktan sonra sistem, klasik bir PID davranışı sergileyerek kompresör devrini yaklaşık 4000-6000 rpm aralığında tekrarlı (testere dişi biçimli) bir modülasyonla değiştirmiştir. Bu davranış, kompresörün ayrık kapasite basamaklarıyla çalıştığı ve PID çıkışının, biriken küçük hataları telafi etmek amacıyla kompresörü periyodik olarak devreye alıp kapasitesini düşürdüğü bir "görev döngüsü" (duty-cycling) modülasyonu olarak yorumlanabilir. Bu salınıma paralel olarak PRESSUREHIGH değeri de senkronize biçimde 11-13 bar aralığında salınmış; bu durum, yoğuşma basıncının kompresör devrine doğrudan bağlı olduğunu doğrulamaktadır. Kompresör akımı (Comp_Current) da bu evrede devirle uyumlu biçimde dalgalanma göstermiştir.

Dikkat çekici biçimde, kompresör devrindeki bu belirgin salınıma rağmen TEMPIN ve TEMPOUT değerleri bu evrede görece düz bir seyir izlemiş ve yaklaşık 19-22°C bandında sabit kalmıştır; bu durum, sistemdeki ısıl kütlenin (sıvı tankı, akışkan hacmi) bir tampon görevi görerek kompresör devrindeki hızlı salınımların doğrudan sıcaklık sinyaline yansımasını sönümlediğini göstermektedir. Sonuç olarak sistem, hedef sıcaklığı başarıyla yakalamış ve test boyunca (yaklaşık 400 saniyelik gözlem penceresinde) stabil bir şekilde muhafaza etmiştir.

4.4. Sıcaklık Homojenliği (TEMPIN – TEMPOUT Farkı)

BTMS içerisindeki farklı ölçüm noktaları arasındaki sıcaklık farkı, çalışmanın amaç bölümünde belirtilen homojenlik sorusuna yanıt vermek amacıyla ayrıca değerlendirilmiştir. Test boyunca TEMPIN ile TEMPOUT arasındaki fark, başlangıçta yaklaşık 1,5-2°C (26°C'ye karşı 24-25°C) seviyesindeyken, kararlı rejimde de benzer biçimde yaklaşık 2°C (21-22°C'ye karşı 19-20°C) seviyesinde kalmıştır. Bu farkın test boyunca büyümeden, dar bir bantta sabit kalması, BTMS ünitesinin akışkan dağıtımının ve soğutma plakası tasarımının modül içerisinde göreli olarak homojen bir sıcaklık dağılımı sağladığına işaret etmektedir. Bu bulgu, giriş bölümünde tartışılan ve sıcaklık farkının hücreler arası dengesiz yaşlanmayı hızlandırdığını gösteren literatürle [3] birlikte değerlendirildiğinde, test edilen ünitenin paket ömrü açısından olumlu bir gösterge sunduğu söylenebilir.

4.5. Enerji Göstergeleri: Kompresör Akım-Gerilim ve Fan Davranışı

Kompresör besleme gerilimi (Comp_Voltage) test boyunca sabit kalarak, kompresörün değişken bir DC/AC bara geriliminden değil, sabit bir güç kaynağından beslendiğini ve devir kontrolünün yalnızca frekans/komut sinyali üzerinden gerçekleştirildiğini doğrulamaktadır. Kompresör akımı (Comp_Current) ise beklendiği gibi devirle orantılı biçimde artıp azalmış, kararlı rejimdeki devir salınımına paralel bir dalgalanma göstermiştir. BTMS-On-Off-Enable sinyali test boyunca sistemin sürekli devrede (enable) kaldığını teyit etmiştir. Fan devrinin testin neredeyse tamamında sabit ~900 rpm'de tutulması, bu ünitede kondenser tarafı ısı reddi kapasitesinin fan devriyle değil öncelikle kompresör devriyle (dolayısıyla soğutkan gaz debisiyle) ayarlandığına işaret etmekte; bu durum enerji tüketimi açısından fanın sabit bir taban yük oluşturduğu, ana enerji tüketim değişkeninin kompresör olduğu şeklinde yorumlanabilir.

5. TARTIŞMA

Elde edilen bulgular, test edilen BTMS ünitesinin 3,6 kW güç seviyesinde, literatürde lityum-iyon hücreler için genel kabul gören güvenli çalışma aralığının (yaklaşık 20-30°C) alt sınırına yakın, hatta zaman zaman bu aralığın hemen altında (~19-20°C) bir sıcaklık bandı sağladığını göstermektedir. Bu durum, yüksek güçte ve hızlı şarj senaryolarında ek bir güvenlik marjı sunması açısından olumlu değerlendirilebilir; ancak set noktasının çok düşük seçilmesi durumunda, düşük ortam sıcaklıklarında PTC ısıtıcı devresinin daha sık devreye girmesi ve dolayısıyla toplam enerji tüketiminin artması olası bir dezavantaj olarak göz önünde bulundurulmalıdır. Sistemin sağladığı ~2°C'lik sınırlı giriş-çıkış sıcaklık farkı, sıvı soğutma plaka tabanlı BTMS teknolojilerinin literatürde vurgulanan temel avantajlarından biri olan yüksek sıcaklık homojenliği ile örtüşmektedir [4].

Kararlı rejimde gözlemlenen kompresör devri salınımı (4000-6000 rpm arası testere dişi modülasyon), PID kontrolcünün beklenen davranışıyla genel olarak uyumlu olmakla birlikte, bu salınımın genliğinin azaltılması hem kompresörün mekanik yorulma ömrü hem de enerji verimliliği açısından iyileştirme fırsatı sunmaktadır. Bu kapsamda; (i) PID kazançlarının (özellikle Ki ve Kd) kademeli kazanç (gain scheduling) veya otomatik ayarlama yöntemleriyle yeniden optimize edilmesi, (ii) aktüatör doygunluğuna karşı anti-windup mekanizmalarının güçlendirilmesi, (iii) türev teriminde sensör gürültüsünü bastıracak bir alçak geçiren filtrenin uygulanması ve (iv) mümkünse ayrık kapasiteli kompresör yerine tam değişken hızlı (inverter) bir kompresör kullanılarak modülasyonun daha yumuşak bir eğri hâline getirilmesi önerilmektedir. Ayrıca yüksek kapasite platosu evresinde (t≈270-480 s) gözlemlenen ikincil devir artışı, sistemin ısıl ataletle (sıvı tankı, plaka kütlesi) etkileşiminin daha ayrıntılı biçimde modellenmesi gerektiğine işaret etmekte; bu durum ileri PID ayarlama çalışmalarında dikkate alınmalıdır.

Bu çalışmanın bazı sınırlılıkları bulunmaktadır. Test, tek bir güç seviyesinde (3,6 kW) ve tek bir tekrarda gerçekleştirilmiş; ortam sıcaklığı gibi sınır koşulları çalışma kapsamında raporlanmamıştır.

Ayrıca sıcaklık homojenliği yalnızca giriş ve çıkış sıcaklıkları üzerinden, iki nokta bazında değerlendirilmiş, batarya paketi içerisindeki hücre bazlı sıcaklık dağılımı doğrudan ölçülmemiştir. Bu sınırlılıklar, gelecekteki çalışmalarda farklı güç seviyelerinin (örneğin düşük, orta ve yüksek güç senaryolarının) karşılaştırmalı biçimde test edilmesi, çok noktalı hücre içi sıcaklık ölçümünün yapılması ve uzun dönemli tekrarlı testlerle PID kontrol kararlılığının istatistiksel olarak doğrulanması yönünde araştırma fırsatları sunmaktadır.

6. SONUÇ

Bu çalışmada, yüksek hacimli bir batarya paketi için tasarlanmış, soğutkan gaz tabanlı ve kapalı çevrim PID kontrollü aktif bir BTMS ünitesinin termal performansı, 3,6 kW sabit güç yükü altında deneysel bir test düzeneği üzerinde incelenmiştir. BTMS ünitesinin mekanik bileşenleri (fan, kondenser, kompresör-akümülatör grubu, kontrol kutusu, gaz ve sıvı hatlarından oluşan akışkan devresi ve kompresör devrini yöneten PID kontrol mimarisi (oransal, integral ve türev bileşenleriyle) ayrıntılı biçimde açıklanmıştır. Deneysel bulgular, sistemin başlangıçtaki hızlı geçici rejim evresinin ardından batarya çıkış sıcaklığını yaklaşık 19-22°C bandında, literatürde genel kabul gören güvenli çalışma aralığı (~20-30°C) içerisinde veya bu aralığa çok yakın biçimde kararlı hâle getirdiğini; bu kararlılığı yaklaşık 400 saniyelik gözlem penceresi boyunca PID tabanlı kompresör devir modülasyonuyla koruduğunu ve giriş-çıkış sıcaklık farkını yaklaşık 2°C ile sınırlı tutarak modül içi sıcaklık homojenliği açısından olumlu bir performans sergilediğini ortaya koymuştur. Bu bulgular, test edilen BTMS ünitesinin yüksek hacimli batarya paketlerinde belirtilen güç seviyesinde etkin, güvenli ve enerji açısından makul bir termal kontrol sağladığını deneysel olarak doğrulamaktadır. Gelecek çalışmalarda farklı güç seviyelerinde ve farklı ortam koşullarında gerçekleştirilecek ek testler ile PID kazançlarının ince ayarının yapılması, sistemin hem termal performansını hem de enerji verimliliğini daha da iyileştirebilecektir.

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VİSKON KUMAŞLARA DENDRİMER İLE KİMYASAL MODİFİKASYON YOLUYLA AROMATERAPİ ÖZELLİĞİ KAZANDIRILMASI

IMPARTING AROMATHERAPY PROPERTIES TO VISCOSE FABRICS THROUGH CHEMICAL MODIFICATION WITH DENDRİMERS

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ÖZET

Bu çalışmada, viskon kumaşlara dendrimer ile kimyasal modifikasyon uygulanarak aromaterapi özelliği kazandırılması amaçlanmıştır. Çalışmada %100 viskon süprem örme kumaşlar kullanılmış ve kumaşlar amin uç gruplarına sahip birinci jenerasyon PAMAM dendrimer ile modifiye edilmiştir. Dendrimer uygulaması sonrasında kumaşlara lavanta yağı emdirilerek aromatik özellik kazandırılmıştır. Koku kalıcılığının belirlenmesi amacıyla belirli zaman aralıklarında subjektif değerlendirme yapılmış ve elde edilen veriler istatistiksel olarak analiz edilmiştir. Varyans analizi sonuçları, hem dendrimer uygulamasının hem de sürenin koku yoğunluğu üzerinde istatistiksel olarak anlamlı etkiye sahip olduğunu göstermiştir ($p<0,05$). Dendrimer ile modifiye edilen kumaşların, işlem görmemiş kumaşlara kıyasla daha yüksek koku kalıcılığı sergilediği belirlenmiştir. Sonuçlar, dendrimerlerin dallanmış yapıları sayesinde koku moleküllerini bünyelerinde tutarak kontrollü salınım sağlayabildiğini ortaya koymuştur. Bu çalışma, viskon kumaşlarda dendrimer kullanılarak aromaterapi özelliği kazandırılabileceğini göstermekte ve fonksiyonel tekstiller alanına katkı sağlamaktadır.
Anahtar Kelimeler: Dendrimer, viskon, aromaterapi, kontrollü salınım, fonksiyonel tekstil.

ABSTRACT

This study aimed to impart aromatherapy properties to viscose fabrics through chemical modification using dendrimers. In the study, 100% viscose single jersey knitted fabrics were used and modified with first-generation PAMAM dendrimers containing amine terminal groups. After the dendrimer treatment, lavender essential oil was impregnated into the fabrics to provide aromatic functionality. Subjective evaluations were conducted at specific time intervals to determine fragrance retention, and the obtained data were statistically analyzed. Analysis of variance (ANOVA) results showed that both dendrimer treatment and time had a statistically significant effect on fragrance intensity ($p < 0.05$). It was determined that dendrimer-modified fabrics exhibited higher fragrance retention compared to untreated fabrics. The results demonstrated that dendrimers, owing to their highly branched structures, can retain fragrance molecules within their architecture and provide controlled release. This study shows that aromatherapy functionality can be imparted to viscose fabrics through the use of dendrimers and contributes to the development of functional textiles.
Keywords: Dendrimer, viscose, aromatherapy, controlled release, functional textiles.

1. GİRİŞ

Yakın geçmişte yüksek derecede dallanmış makromoleküllerin özelliklerinin, nadiren kısa ya da uzun dallar içerebilen lineer polimerlerinkinden çok farklı olduğu bulunmuştur (Klajnert ve Bryszewska, 2001). Düzenli olarak dallanmış insan yapımı moleküllerin yeni bir sınıfı dendrimerlerdir (Dastjerdi ve Montazer, 2010). Bunlar yeni gelişen nano-teknolojide çok önemli rol oynamaktadır.

Dendrimerlerin ağaca benzer yapıları ve yüzey fonksiyonellikleri, bunların nano ölçeklerde çok kullanışlı yapı elemanları ve taşıyıcı moleküller olmalarını sağlamaktadır (Sarkar v.d., 2005). Dallanmış makromoleküller ya da dendrimerler hem inovatif kimya hem de inovatif uygulamalar bağlamında zengin bir araştırma kaynağı sunmaktadır (Rosace v.d., 2007). Dendrimerler için daha yeni sayılabilecek uygulama alanlarından birisi de tekstil terbiyesi işlemleridir (Atav ve Yavaş, 2010).
Dendrimerlerin tekstil alanında kullanımına ilişkin literatürde özellikle reaktif boyalarla tuzsuz boyama eldesi ve su iticilik üzerine çalışmalar olduğu görülmektedir. Bunun ötesinde çeşitli fonksiyonel tekstiller eldesinde de dendrimer kullanımına rastlanmaktadır. Barış ve Atav (2012) ile Atav ve ark. (2017) tarafından yapılan çalışmalarda dendrimer aplike edilmiş sırasıyla pamuklu ve yünlü kumaşların daha iyi koku kalıcılığına sahip olduğu ortaya koyulmuştur. Bu çalışmada ise viskon kumaşlarda kontrollü koku salınımı sağlamada Dendrimerlerin kullanım imkânları araştırılmıştır. Viskon kumaşların dendrimer ile modifikasyonuna ilişkin literatürdeki çalışmalar oldukça sınırlıdır. Staneva ve ark. (2019) yeni bir PPA dendrimer ile modifiye edilmiş viskon kumaşın gram-pozitif bakteri *B. cereus* ve maya türü *C. Lipolytica*'ya karşı iyi düzeyde antimikrobiyal aktivite gösterdiği saptanmıştır. Ancak literatürde viskon kumaşlarda dendrimer kullanımı ile kontrollü koku salınımın incelendiği bir çalışmaya rastlanmamıştır. Bu nedenle çalışmanın özgün olduğu ve literatüre katkı sağlayacağı düşünülmektedir.

2. MATERYAL VE METOD

Denemelerde %100 viskon süprem örme kumaşlar kullanılmıştır. Denemelerde Sigma-Aldrich firmasına ait amin uç gruplara sahip 1. jenerasyon PAMAM dendrimer kullanılmıştır.
2 g/L dendrimer içeren pH'ı 5'e ayarlanmış (asetik asit ile) çözeltiyle 1:10 flotte oranında 50 °C'ta 30 dk süreyle işlem yapılmıştır. Daha sonra işlem görmüş ve görmemiş viskon kumaşlara koku aplikasyonu yapılmıştır. Koku aplikasyonu için; 5 mL lavanta yağı 45 mL etil alkolün içinde çözülmüş ve fulardda kumaşa Af %80 olacak şekilde aplike edilmiştir. Ardından kumaşlar oda sıcaklığında serbest hâlde kurumaya bırakılmıştır.
Koku testi: Koku değerlendirmesi 10 kişilik bir panel tarafından gerçekleştirilmiştir. 1-5 arası bir not vermeleri istenmiştir. Daha sonra 10 kişinin verdiği değerlerin ortalaması alınmıştır. Skala olarak 1-5 arası değerlendirme kullanılmış olup, koku skalası şu şekildedir;
1: Kokusuz, 2: Hafif kokulu, 3: Orta kokulu, 4: Fazla kokulu, 5: Aşırı kokulu

3. BULGULAR VE TARTIŞMA

Bu çalışmada kumaşlara dendrimer ile işlem yapılmasının ve sürenin koku kalıcılığı üzerine etkisi istatistiksel olarak incelenmiş olup elde edilen varyans analizi sonuçları Tablo 1'de verilmektedir.

Tablo 1: Dendrimer ile işlem ve süre parametrelerine ilişkin varyans analizi sonuçları

Kaynak	DF	Adj SS	Adj MS	F-Değeri	P- Değeri
Dendrimer	1	3,600	3,6000	7,41	0,010
Süre	3	17,800	5,9333	12,22	0,000
Hata	35	17,000	0,4857		
Toplam	39	38,400			

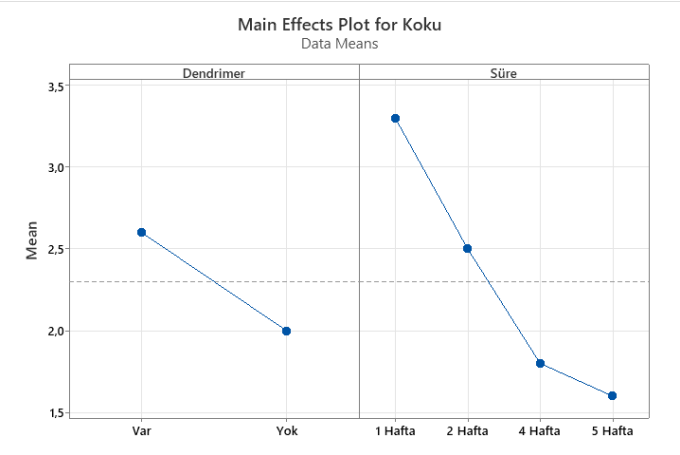
Tablo 1 incelendiğinde gerek dendrimer ile ön işlem yapılmasının gerekse de sürenin koku kalıcılığı üzerine etkisinin istatistiksel olarak önemli ($p<0,05$) olduğu görülmektedir. Bu durum normal viskon kumaş yerine dendrimerle kimyasal modifikasyona uğratılmış viskon kumaş kullanıldığında aplike edilecek olan kokunun daha uzun süre kalıcı olacağını ortaya koymaktadır. Dendrimerler dallı budaklı yapılar olup koku moleküllerini dalları arasında tutma özelliğine sahip olduklarından kokunun kontrollü salınımını sağlamaktadırlar. Bu durum daha önce pamuklu ve yünlü kumaşlar üzerinde ***Barış ve Atav (2012)*** ile ***Atav ve ark. (2017)*** tarafından yapılan çalışmalarda da ortaya koyulmuştu.
Tablo 1 incelendiğinde görülen bir diğer sonuç sürenin de koku yoğunluğu üzerine etkisinin istatistiksel olarak önemli ($p<0,05$) olduğudur.

Farkın kaynağını görmek için Tukey analizi de yapılmış olup sonuçlar Tablo 2'de verilmektedir. Bu sonuçlar, sürenin artmasıyla birlikte kumaş üzerindeki uçucu koku bileşenlerinin ortam havasına difüzyonu nedeniyle koku yoğunluğunun azaldığını göstermektedir.

Tablo 2: Süre faktörü için Tukey analizi sonuçları

Süre	N	Ortalama	Grup		
1 Hafta	10	3,3	A		
2 Hafta	10	2,5	A	B	
4 Hafta	10	1,8		B	C
5 Hafta	10	1,6			C

Elde edilen sonuçların daha açık bir şekilde görülmesi için Koku için Ana Etkiler Grafiği çizilmiş olup sonuçlar Şekil 1'de verilmektedir.



Şekil 1: Koku için Ana Etkiler Grafiği

4. GENEL SONUÇ

Bu çalışmada viskon kumaşların PAMAM dendrimer kullanılarak kimyasal olarak modifiye edilmesi ve aromaterapi özelliği kazandırılması araştırılmıştır. Elde edilen sonuçlar, dendrimer ile ön işlem uygulanmasının koku kalıcılığını anlamlı düzeyde artırdığını göstermiştir. Varyans analizi sonuçlarına göre hem dendrimer uygulaması hem de depolama süresi koku yoğunluğu üzerinde istatistiksel olarak anlamlı etkiye sahiptir ($p<0,05$).

Dendrimer ile modifiye edilen kumaşlarda koku moleküllerinin dendrimer yapısında tutulabildiği ve bu sayede kontrollü salınım gerçekleştiği düşünülmektedir. Buna bağlı olarak işlem görmüş kumaşların daha uzun süre koku özelliğini koruduğu belirlenmiştir. Sürenin artmasıyla birlikte tüm numunelerde koku yoğunluğunda azalma meydana gelmiş olsa da dendrimer uygulanmış kumaşlar daha yüksek koku seviyelerini muhafaza etmiştir.

Sonuç olarak PAMAM dendrimerlerin viskon kumaşlarda aromaterapi amaçlı kontrollü koku salınımı sağlamak için kullanılabilecek bir kimyasal modifikasyon ajanı olduğu belirlenmiştir. Çalışma, viskon esaslı fonksiyonel tekstillerin geliştirilmesine yönelik yeni bir yaklaşım sunmakta olup ilerleyen çalışmalarda farklı dendrimer jenerasyonlarının, farklı esansiyel yağların ve yıkama dayanımının araştırılması önerilmektedir.

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ASSESSMENT OF ANIMAL WELFARE IN DAIRY CATTLE USING ARTIFICIAL INTELLIGENCE AND COMPUTER VISION TECHNOLOGIES

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ABSTRACT
Regular assessment of animal welfare in dairy farms is becoming increasingly important for animal health, productivity, and sustainable production. Conventional welfare assessment methods generally rely on observations by farmers or trained assessors and may therefore be time-consuming, labor-intensive, and partly observer-dependent. Recent developments in precision livestock farming have considerably increased the use of artificial intelligence, machine learning, deep learning and computer vision in dairy production. Withstandard RGB (Red-Green-Blue) cameras, depth-sensing cameras, thermal cameras, and image analysis systems, individual animal identification and tracking can bedonewithout direct contact. Welfare-related indicators such as lameness, lying and standing behaviors, feeding behavior, body condition, respiration rate, heat stress, and social behaviors can be continuously monitored. However, accurate recognition of a particular behavior by an artificial intelligence system does not necessarily represent a complete assessment of animal welfare. Data from computer vision systems should therefore be interpreted alongside validatedanimal-based welfare indicators, environmental conditions, and herd-management information. This review discusses current applications, advantages, limitations, and future perspectives of artificial intelligence and computer vision technologies for assessing dairy cattle welfare.
Keywords: Dairy cattle, Animal welfare, Artificial intelligence, Precision livestock farming, Deep learning

1. INTRODUCTION
Animal welfare is not only an ethical issue in modern dairy farming but also a fundamental factor in animal health, production performance, herd lifespan, and the sustainability of the operation. Current welfare approaches consider health, behavior, and the animal's mental state, along with adequate nutrition and suitable environmental conditions (Tuvay and Ermetin, 2023). The Five Domains Model proposes that nutrition, physical environment, health, and behavioral interactions affect the animal's mental state (Mellor et al., 2020). The European Food Safety Authority also considers conditions such as lameness, mastitis, limited mobility, resting problems, and metabolic disorders as important welfare problems in dairy cattle (EFSA AHAW Panel, 2023).
Dairy farm welfare evaluation generally relies on animal-, environmental-, and management-based indicators. Body condition, lameness, skin lesions, cleanliness, disease incidence, animal behavior, andhuman-animal interactionsare important animal-based indicators. However, traditional assessments do not allow continuous monitoring because herds must be visited at specific times, and observers must score animals. Furthermore, as farms grow, it becomes increasingly difficult to observe all animals individually and regularly (Özçelik Metin and Asan, 2016; Leliveld and Provolo, 2020; Silva et al., 2021).
This need has accelerated the development ofPrecision Livestock Farming (PLF) systems. In precision livestock farming, the aim is tocontinuously monitor individualanimals' health, behavior, welfare, and productivity by analyzing data from sensors, cameras, and automated recording systems using artificial intelligence and machine learning methods (Lovarelli et al., 2020; Trapanese et al., 2025). In Turkey, the use of digital technologies in dairy farmingis receiving increasing attention. Sensors, automated milking systems, artificial intelligence, and computer vision are being evaluated for herd management(Akıllı and Atıl, 2014; Kılıçkaya et al., 2026).
Computer vision is based on the automatic identification, tracking, and analysis of animal behaviorfrom camera images. In recent years, the use of computer vision in dairy farming has expanded significantly,

especially with the development of convolutional neural networks (CNNs), models from the YOLO family, pose estimation, and Transformer-based methods (Chen et al., 2021; Antognoli et al., 2025; Islam et al., 2026).

Artificial intelligence and imaging technologies are increasinglyused in dairy cattle managementto identify welfare-related behavioral and physiological changes early. Borchers et al. (2017) predicted calving time with high accuracy by using machine learning to evaluate sensor data on activity and lying behaviors. Similarly, Fuentes et al. (2020, 2021) reported that analyzing environmental and physiological data with artificial intelligence can support heat-stress management and predict milk yield and milk quality. These studies show that artificial intelligence-based systems can support continuous, objective monitoring of animal welfare.

Artificial intelligence methods are also widely used to predictmilk yield and reproductive traits and to detect disease. Grzesiak et al. (2006), Görgülü (2012) and Takma et al. (2012) reported that artificial neural networks canoutperform classical regression methods inpredicting lactation milk yield. Çetin and Mikail (2016) stated that artificial neural networks are an effective methodfor dataprocessing and prediction applications in dairy cattle farming, while Memmedova (2012) showed that this approach can also beused to detect subclinical mastitis. These AI-based applications can support animal welfare assessmentby enabling early disease detection, monitoring changes in the health and performance of individual animals, and timely identification of potential welfare issues.

Image analysis and artificial intelligence are also used to estimate body weight without physical contact. In addition to approaches based on traditional body measurements (Reis et al., 2008; Bretschneider et al., 2014; Franco et al., 2017), image-based technologies have also been applied to cattle monitoring (Barbedo and Koenigkan, 2018). Gjergji et al. (2020) stated that convolutional neural networks can estimate cattle body weight from images alone, and thatthis approach may reduce labor and animal handling associated with conventional weighing.

2. THE ROLE OF COMPUTER VISION AND ARTIFICIAL INTELLIGENCE IN ANIMAL WELFARE

While traditional camera systems mostly rely on human interpretation, AI-powered computer vision systems can automatically identify animals in an image, track individuals, and classify the behavior shown. For this purpose, researchers use RGB (Red-Green-Blue) cameras that providestandard color images, RGB-D or depth cameras that provide depth information, and thermal cameras that detect differences in the animal's surface temperature.

Current computer vision systems can identify and track individual cattle; classify behaviors such as feeding, drinking, lying, standing, and walking; and assess welfare-related traits such as lameness, body condition score, respiration rate, and selected social behaviors (Antognoli et al., 2025; Islam et al., 2026). Today, research is moving from simply detectingan animal in an image to analyzing behavioral patterns over time. However, it is not accurate to directly interpret a classification made by artificial intelligence, such as "the cow is lying down," "the cow is walking," or "the cow is eating," as "the animal's welfare is good or bad." Welfare is a multidimensional concept andcannot be fully assessed using a single technology (Weary and von Keyserlingk, 2023). Therefore, technology should primarily enable objective, continuous, individual-level measurement of welfare-related indicators.

3. EVALUATION OF WELFARE INDICATORS WITH COMPUTER VISION

3.1. Lameness Detection

Lameness isa major animal welfare problemin dairy cows because it causes pain and difficulty in movement. In lame animals, the gait, stride length, back posture, walking speed, andweight distribution among the limbscan change. Assessmentsin Turkey also emphasize that lameness significantly affects an animal's behavior and welfare (İzci et al., 2021).

In traditional locomotion scoring, trained personnel evaluate animal gait, while computer vision systems canautomatically estimate the positionsof the backline, head, legs, joints, and hooves from video images. Barney et al. (2023) developed an automated lameness detection system that uses deep learning and pose estimation to evaluate multiple cattle simultaneously.

Such approaches are particularly important in large herdsbecause they enable frequent assessment and may supportearlier detection of lameness.

The main advantage of automated lameness systems is that they not only determinelameness prevalencebut also trackchanges in individual animals over time. However, different walking surfaces, the animal's walking angle, partialocclusion, camera position, and differences in body structure between breeds can affect algorithm accuracy.

3.2. Lying, Standing, and Movement Behaviors

In dairy cattle, resting and lying behaviors are important indicators for assessing animal welfare. A significant decrease in lying time may indicate housing discomfort, lameness, heat stress, or disease. In contrast, it is important to evaluate not only the total duration of the behavior but also characteristics such as the number and duration oflying bouts.

Porto et al. (2013) developed one of the early computer vision applications that automatically identifies lying-down behavior from camera images in free-stall dairy cattle barns. Today, deep learning algorithms can classify behaviors such as lying down, standing, walking, and feeding simultaneously within the same image (Chen et al., 2021; Islam et al., 2026).

Continuous video analysis offers significant advantages over classical observation methods, especially at night and when personnel are not present on the farm. Thus, changes in the animal's daily activity budget can be determined, and early warnings can be generated for animals at risk of developing welfare or health problems.

3.3. Monitoring Feeding Behavior

Feeding duration, feeder-visit frequency, and changes in daily feeding patterns provide valuable information on health and welfare. Factors such as disease, lameness, social competition, and heat stress can change feeding behavior.

Giannone et al. (2025) studied individual identification of dairy cows and automatically evaluatedtheirfeeding behaviorusing a YOLOv8-based computer vision model. Such systems can automatically record the time an animalspends at the feeder, the number of feeder visits, and changes in feeding routines.

However, many animals in the feeder area at the same time, occlusion among animals, and changes in viewing angle are significant problems for individual tracking. Therefore, combining camera data with RFID or activity sensor data may provide more reliable results in the future.

3.4. Assessment of Body Condition

Body condition score (BCS)indicates dairy cows' body energy reserves and is closely related to feeding, health, fertility, and welfare. Traditional BCS assessment relies ona trained assessorobserving specific anatomical regions of the animal, which can lead to differences among observers.

Three-dimensional camera systems enable automatic BCS estimation by identifying shape characteristics in the lumbar, rump, hip, andtailhead regions. Spoliansky et al. (2016) performed automatic BCS estimation using a low-cost Kinect 3D camera; Song et al. (2019) improved the method using three-dimensional features from different body regions. Albornoz et al. (2022) also showed that commercial three-dimensional camera systems can monitor condition changes in dairy cows.

One important advantage of automatic BCS is that animals can be evaluated not only at specific periods but also daily, for example, at the milking-parlor exit. This enables earlier detection of excessive loss of body condition.

3.5. Respiration Rate, Thermal Imaging, and Heat Stress

Heat stress can adversely affect feed intake, milk yield, fertility, health, and welfare in dairy cattle. An increased respiration rate is a common physiological response to heat stress that facilitates heat dissipation. Traditionally, respiration rate assessment has requiredobservers to count the animal's chest or abdominal movements, but it is now possible to determine these movements automatically from RGB video images. Shu et al. (2024) estimated the respiration rate of multiple cows in a free-stall barn using a non-contact computer vision method and showed its applicability to heat-stress monitoring. Wang et al. (2024) estimated respiration rate from RGB videos using a Transformer-based approach. Infrared thermography can also measure surface temperature without physical contact at the animal's eyes, nose, udder, feet, or other anatomical regions.

Combining thermal imaging with machine learninghas been investigated for the early detection of heat stress andhealth problems such as mastitis andlimb disorders (Wang et al., 2023). Current assessments show that orbital, nasal, and mammary regions, in particular, can be used to monitor thermal status in cattle (Sousa Pinto et al., 2026).

3.6. Social Behavior and Welfare Indicators

Dairy cattle are social animals, and proximity within a group, allogrooming, courtship, loitering, and interactions with other individuals canhelp assess welfare status. Computer vision systems that recognize animals individually and track them over time enable automatic analysis of social relationships within the herd.

Parivendan et al. (2025) reported that combining deep learning with social network analysis can allow for a more detailed examination of individual relationships, competition, and social interactions in dairy cattle. Fuentes et al. (2026) noted that although artificial intelligence systems can successfully identify basic behaviors such as walking, lying down, or feeding, they are still insufficient in explaining the context of behavior in terms of welfare. For example, lying down can be normal rest, but it can also occur because of illness or difficulty moving. Similarly, animals being close to each other can indicate a positive social relationship, but it can also reflect resource scarcity. Therefore, in the future, the goal should not be simply "what is the animal doing?" The focus should not be solely on answering why this behavior occurred, but also on evaluating how it affects welfare.

3.7. Estrus Detection

Another application of artificial intelligence is estrus detection. Cavero et al. (2008) reported 99.6% accuracy in estrus detection using artificial neural networks; Brunassi et al. (2010) reported 84.2% accuracy using a fuzzy logic model; and Memmedova and Keskin (2011) reported 98% accuracy. Yıldız (2016) emphasized that including environmental variables such as temperature and humidity, in addition to mobility data, can improve prediction accuracy.

4. ADVANTAGES AND LIMITATIONS

The main advantages of using AI-supported computer vision systems in dairy farming are that they do not require physical contact with animals, enable simultaneous monitoring of many animals, collect data 24 hours a day, and reduce differences associated with human observation. These systems can also enable early detection of deviations from normal behavioral patterns and provide automatic alerts to farm staff. However, several problems must be solved for successful implementation in commercial operations. Changes in lighting conditions, camera angle, barn contamination, occlusion among animals, the presence of animals of different breeds and body structures, and differences in housing between operations can affect model performance. An algorithm that performs well in one operation or on a limited number of animals is not guaranteed to perform the same way in a different operation (Antognoli et al., 2025).

In addition, image storage, datasecurity, system cost, internet infrastructure, andfarmers' abilityto use the technology also affect adoption. More importantly, technology can improve animal welfare only if the system's information is turned into sound management decisions. Dawkins (2021) emphasizes that smart livestock technologies do not automatically increase welfare; the technology should identify and meet the animal's needs.

5. CONCLUSION AND FUTURE PERSPECTIVE

Artificial intelligence and computer vision technologies offerapplications for monitoringanimal welfare in dairy cattle. Throughautomated analysis of camera images, many animal-based indicators such as lameness, lying and standing behaviors, feeding, body condition, respiration rate, heat stress, and social behaviors can beevaluated continuously andwithout physical contact. However, computer vision systems should first reliably measure scientifically validated welfare indicators before generating a general welfare score. Because animal welfare is multidimensional, a single image-based indicator alone cannot describe overall welfare status. Therefore, combining camera images with different datasources such as milk yield, rumination activity, activity sensors, ambient temperature and humidity,and disease and treatment records is important. In the future, it may be possible to create individual and dynamic welfare profiles for each animal by integrating multiple sensor data through artificial intelligence.

To do so, the developed models need validation across different farms, housing systems, anda sufficient number of animals. In conclusion, artificial intelligence and computer vision should be viewed not as systems that replacefarmers or animal welfare professionals, but rather as tools that continuously monitor animals, identify risks early, and support management decisions.

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MECHANICAL VENTILATION AND COOLING TECHNOLOGIES TO MITIGATE HEAT STRESS IN DAIRY CATTLE HOUSING

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ABSTRACT
Heat stress in dairy cattle is an important environmental problem that negatively affects milk yield, feed intake, reproductive performance, health and animal welfare. Increased metabolic heat production in high-yielding dairy cows reduces their ability to dissipate excess body heat during hot weather. In addition to shading and appropriate shelter design, mechanical ventilation and water-based cooling systems are widely used to reduce heat stress. This review summarizes mechanical ventilation, fan systems, tunnel and cross ventilation, sprinkler/soaker, fogging and evaporative cooling applications, and sensor-controlled precision cooling approaches used in dairy cattle shelters. Current studies show that combining fans with direct wetting can reduce body temperature and respiration rate, preserve milk yield, and, with appropriate design, increase water-use efficiency. However, cooling success depends on ambient temperature and relative humidity, air speed, fan placement, water flow rate, spray duration, and the system's control logic. In recent years, researchers have developed automatic systems using the temperature-humidity index, wearable sensors, thermal imaging, and computer vision data. The most applicable short-term approach for commercial dairy farms is to manage existing fan and sprinkler/soaker systems more effectively with environmental sensors and simple automatic control mechanisms.
Keywords: Dairy cattle, Heat stress, Mechanical ventilation, Evaporative cooling, Precision cooling

1. INTRODUCTION
Dairy cattle are homeothermic animals that maintain their body temperature within narrow limits. However, heat stress occurs when the environmental and metabolic heat loads exceed the animal's capacity to dissipate heat. Heat production increases-particularly in high-yielding cows-due to elevated feed intake and metabolic activity. Consequently, modern dairy cows can be more susceptible to hot environmental conditions (Kadzere et al., 2002; West, 2003; Becker et al., 2020).
Heat stress affects more than milk yield. Common consequences include decreased feed intake, elevated respiration rates and body temperatures, altered lying and feeding behaviors, impaired reproductive performance, and reduced welfare (Polsky and Von Keyserlingk, 2017; Becker et al., 2020). Furthermore, performance and reproductive losses associated with heat stress have long been recognized as imposing a significant economic burden on dairy operations (St-Pierre et al., 2003).
One of the most common environmental indicators used to assess heat stress is the Temperature-Humidity Index (THI). However, because THI relies solely on temperature and relative humidity, it does not directly reflect factors such as air velocity, solar radiation, milk yield, stage of lactation, and individual susceptibility (Dikmen and Hansen, 2009; Ji et al., 2020). Monitoring THI and implementing appropriate herd management strategies are crucial for protecting dairy cattle from the adverse effects of heat stress (Ermetin et al., 2023). In a classic study in a Mediterranean climate, milk yield and dry matter intake declined significantly as THI rose from 68 to 78 (Bouraoui et al., 2002).
According to the traditional THI classification proposed by Armstrong (1994), a THI below 72 indicates no heat stress, while the 72–78 range signifies mild heat stress, the 79–88 range moderate heat stress, and the 89–98 range severe heat stress. The classification of heat stress in dairy cattle based on THI values is presented in Table 1.

Table 1. Classification of heat stress in dairy cattle according to THI values (Armstrong, 1994)

THI value	Heat stress level
< 72	No heat stress
72–78	Mild heat stress
79–88	Moderate heat stress
89–98	Severe heat stress
> 98	Very severe/dangerous heat stress

Studies in Türkiye also show a risk of heat stress for dairy cattle in many regions during the summer. Kibar et al. (2018) in Siirt, Karaca (2021) in Hatay, Sevim and Alarslan (2023) in Aydın-Bozdoğan, and Sarıözkan et al. (2025) in Kayseri, reported that THI values can reach levels associated with heat stress in dairy cattle during the summer months. These findings show that cooling practices may be important not only in coastal regions but also in dairy farms in regions with continental climates. This review summarizes the mechanical ventilation and cooling technologies used to reduce heat stress in dairy cattle shelters in light of current literature.

2. DETERMINATİON OF HEAT STRESS AND HOUSING MICROENVIRONMENT

Air temperature, relative humidity, air velocity, and solar radiation are the primary environmental variables when assessing the housing microenvironment. Although the Temperature-Humidity Index (THI) is widely used in livestock operations because of its practicality and ease of calculation, supplementing environmental indicators with animal-based measurements can yield more reliable results when assessing the actual heat load animals experience (Ji et al., 2020; Oliveira et al., 2025).
Elevated respiration rates and body temperatures are among the early and significant physiological responses observed in dairy cows exposed to heat stress. Additionally, behavioral changes such as reduced feed intake, increased water consumption, prolonged standing, and a preference for cooler areas may occur (Polsky and Von Keyserlingk, 2017; Becker et al., 2020). In recent years, research focused on monitoring these responses using wearable sensors, thermal cameras, radar, and computer vision systems has intensified (Zhang et al., 2024; Oliveira et al., 2025). These advancements are crucial for managing cooling systems based on the animal's actual heat load rather than relying solely on fixed environmental threshold values.

3. MECHANICAL VENTILATION SYSTEMS

The primary objectives of ventilation are to remove warm, humid air from the shelter, supply fresh air, and generate sufficient air movement at the animal level. While natural ventilation relies on wind and temperature differences, mechanical ventilation utilizes fans to enhance air exchange and air velocity. Mechanical ventilation serves as a crucial tool for mitigating heat stress, particularly during hot periods when natural air movement is insufficient (Becker and Stone, 2020; Ji et al., 2020). Figure 1 presents an example of fan-assisted ventilation and cooling.



Figure 1. Fan-assisted ventilation and cooling applications in dairy cattle shelters

Fan-driven air movement increases convective heat loss from the skin surface. However, as ambient temperature approaches skin temperature, convection becomes less effective and evaporative heat loss becomes more important. Therefore, in hot conditions, mechanical ventilation is generally more effective when combined with water-based cooling methods such as sprinklers, soakers, or fogging (West, 2003; Becker and Stone, 2020; Oliveira et al., 2025). In addition to fan capacity, fan orientation and spacing, as well as air speed at cow level, are important. Airflow must effectively cover the shelter volume as well as feeding, resting, and holding areas.

In controlled shelters, tunnels or cross-ventilation systems can create more regular, directional airflow. Evaporative pads or fogging systems can be used with ventilation systems to cool incoming air. However, investment, energy and maintenance requirements are higher than naturally ventilated shelters (Becker and Stone, 2020; Ji et al., 2020).

In recent years, targeted air distribution systems have been developed that aim to direct air directly to the area where the animal is located. Cao et al. (2022) showed that air jets delivered to cows lying in free stalls through perforated air ducts can increase convective heat loss. In a follow-up study of the same system, the exit angle of the air jet, duct diameter, and deflector design affected cooling performance (Cao et al., 2023). Although this approach is promising for energy and air distribution, commercial dairy farms need long-term field data.

4. WATER-BASED COOLING TECHNOLOGIES

Dairy cattle operations use water in two basic ways: to wet the animal directly or to evaporatively cool the air. Direct wetting systems promote heat loss through the evaporation of water from the skin and hair coat. In fogging and evaporative pad systems, the main goal is to reduce air temperature. The more suitable system depends on climate, relative humidity, shelter type, and water resources (Ji et al., 2020; Zhang et al., 2024).

4.1. Sprinkler and Soaker Systems

Sprinkler or soaker systems are generally used along the feedline and in pre-milking holding areas to wet the cows' backs and bodies at regular intervals. When operated with fans, air movement increases cooling by accelerating evaporation of water on the animal's surface. The system's effectiveness depends on water flow rate, nozzle type, spray duration, spray interval, and the rate of water reaching the animal (Chen et al., 2015; Tresoldi et al., 2018a; Zhang et al., 2024). Figure 2 shows the combined use of fan and soaker systems.



Figure 2. Combined use of fan and soaker systems in dairy cattle farming

Chen et al. (2015) compared different flow rates and droplet sizes under hot, dry conditions and showed that water flow rate is more decisive than droplet size in the cooling response. In a follow-up study, the 1.3 L/min flow system produced a similar body temperature and milk yield response to the 4.9 L/min flow system while using about 73% less water (Chen et al., 2016). This result clearly shows that higher water use does not always mean more effective cooling.

Spray duration and on- and off-times are also important. Tresoldi et al. (2018a) found that longer spray durations improved some physiological measures of cooling.

Tresoldi et al. (2018b) reported that increasing spray frequency while maintaining the same total water volume had minimal effects on physiological responses. In contrast, longer spray durations or shorter off-times, which increased total water use, improved cooling responses. A later field study indicated that the biological differences between flow rates of 3.3 and 4.9 L/min were small and that the higher flow rate provided only a limited advantage in milk yield and body temperature (Tresoldi et al., 2019).
In a more recent study, automatic sprinkler systems were used in commercial barns containing 1208 dairy cows; they were associated with decreased body temperature and somatic cell count (SCC), increased dry matter intake (DMI), and higher milk yield (Liu et al., 2024). This study is important as it shows that automatic water applications have practical potential in large flocks. Figure 3 shows examples of individual precision cooling systems.

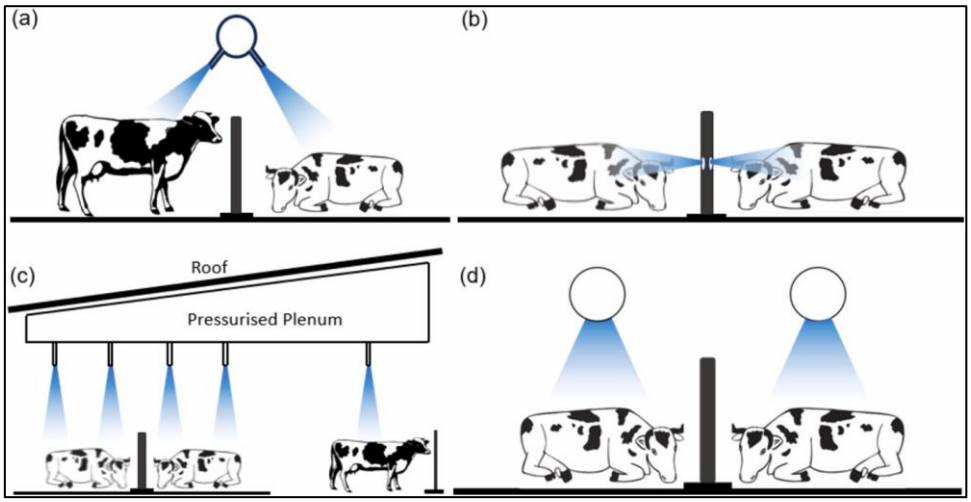


Figure 3. The illustrations of the four types of individual precision cooling systems for cows (Zhang et al., 2024).

4.2. Fogging and Evaporative Cooling

In misting and fogging systems, small water droplets are released into the air, and the shelter air temperature is reduced by evaporating the water. The effectiveness of these methods depends strongly on relative humidity. As humidity increases, the air's capacity to absorb additional water vapor decreases and the evaporative cooling effect weakens (West, 2003; Becker and Stone, 2020).
Almuhanna et al. (2021) found that roof-mounted fogging fans reduced the THI value inside the shelter, but the improvement was limited; they reported that system efficiency should be improved along with shelter design and cooling capacity. Anderson et al. (2013) showed that an adjustable fan-and-mister system designed to track the shifting shaded area reduced core body temperature and increased lying time compared with a stationary system. These results show that not only the presence of equipment matters, but also proper placement and air-water distribution.

5. COMPARISON OF SYSTEMS AND RESOURCE EFFICIENCY

When selecting cooling systems, consider not only physiological cooling success but also water and energy consumption. Drwencke et al. (2020), in their study comparing different cooling strategies, found that the targeted air system used the least water but the most energy; they reported that the optimized fan+spray approach could provide similar physiological and behavioral responses to the traditional system while using about half the water. Therefore, it is not correct to define the 'most effective' system without considering water and energy consumption together. The main ventilation and cooling systems and their general characteristics in dairy cattle shelters are presented in Table 2.

Table 2. General characteristics of the main ventilation and cooling systems in dairy cattle shelters

System	Basic mechanism	Main advantage	Main limitation
Fan / mechanical ventilation	Increases convective heat loss	Simple, widely used, and easy to automate	May be insufficient alone at high temperatures; requires energy
Tunnel/cross ventilation	Provides controlled air exchange and directed airflow	More uniform microenvironment	Requires investment, energy, and maintenance
Sprinkler / soaker + fan	Direct wetting + evaporation + air movement	Effective body cooling; water flow rate can be optimized	Water use, wet flooring, and drainage requirements
Misting / fogging + fan	Evaporative cooling of the air	Effective in hot, dry climates	Effectiveness decreases at high relative humidity
Evaporative pad + fan	Evaporative cooling of incoming air	Potential for a more uniform environment in controlled housing	Requires water, energy, and maintenance

Source: Summarized from Becker and Stone (2020), Ji et al. (2020), Drwencke et al. (2020), Zhang et al. (2024), and Oliveira et al. (2025).

Select an appropriate system by considering the region's climate, shelter openness, stocking density, water quality and quantity, electrical infrastructure, and maintenance capacity. Especially in direct wetting systems, provide adequate drainage and prevent nozzle clogging and irregular water distribution. In fan systems, regularly check whether the targeted airflow reaches the animals.

6. SENSOR-CONTROLLED AND PRECISION COOLING

Most conventional cooling systems apply the same level of cooling to the entire group of animals when a certain air temperature or THI threshold is exceeded. However, cows in the same environment may have different heat loads due to milk yield, stage of lactation, age, health, and individual heat tolerance. In the precision cooling approach, the aim is to combine environmental and animal-based data to direct cooling to the animal, region, or time needed (Zhang et al., 2024).

Zhang et al. (2024) discuss individual precision cooling under three basic components: determining the animal's heat load, applying the appropriate cooling method, and the control mechanism that manages the system. For this purpose, in addition to temperature-humidity sensors, researchers can use wearable sensors, infrared thermography, RGB cameras, computer vision, and radar-based measurements. However, real-time individual control is not yet common in commercial dairy farms, and sensor cost, data processing, and system integration are significant limitations (Zhang et al., 2024; Oliveira et al., 2025).

There are also important developments in terms of control systems. Beyhan (2023) demonstrated that temperature and humidity can be monitored and controlled with low-cost sensors and fans in a scaled dairy cattle barn model, showing the feasibility of PID-based automation. Such studies provide the technical basis for gradually operating existing fan and water systems based on environmental data rather than fixed schedules. The most feasible short-term solution is to automatically and gradually manage fan and sprinkler/soaker systems in commercial dairy farms by connecting them to THI or temperature-humidity sensors.

7. CONCLUSION

Heat stress is an important environmental problem affecting productivity, health, and welfare in modern dairy farming. THI studies in different regions of Türkiye show that cooling requirements during hot periods should be considered in many production regions. Although mechanical ventilation is a basic practice, it may not be sufficient on its own under severe temperature conditions.

Sprinkler or soaker systems with fans are an effective, practical option for direct body cooling. The success of fogging and evaporative pad systems depends especially on relative humidity and shelter design.

More water or higher fan power in cooling systems does not always mean better results. Water flow rate, spray duration, fan placement, air speed and control thresholds must be optimized together. Current studies show that applications such as automatic sprinkler systems and targeted air distribution have significant potential. In the future, current research is increasingly examining precision cooling systems that integrate environmental sensors with animal-based measurements. However, in the short term, sensor-controlled and resource-efficient operation of existing fan and water systems appears to be the most feasible approach for commercial dairy farming.

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IMPORTANCE OF DRY PERIOD MANAGEMENT FOR MASTITIS PREVENTION IN DAIRY CATTLE

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ABSTRACT
The dry period allows mammary tissue to undergo involution and regeneration in preparation for the next lactation. However, it is also a period of increased susceptibility to new intramammary infections. Susceptibility to new intramammary infections is particularly high at the beginning of the dry period and in the weeks preceding calving, and some infections that occur during this period can manifest as clinical or subclinical mastitis after calving, negatively affecting udder health in the next lactation. Therefore, controlling contagious and environmental mastitis pathogens during the dry period is important. In dry-period mastitis control, selective dry cow therapy (SDCT) stands out as an important approach to reduce unnecessary antibiotic use and the risk of antimicrobial resistance. In this approach, antibiotics are administered to cows that are infected or at high risk of infection based on somatic cell count (SCC), clinical mastitis history, and, if necessary, bacteriological culture results, while internal teat sealants, which form a physical barrier in the teat canal, can be used in cows considered uninfected. In addition, reducing milk yield to an appropriate level before dry-off, balanced feeding, hygienic practices, clean and dry housing conditions, and reduced environmental contamination near calving are among the key dry-period management practices for preventing mastitis. This review evaluates the importance of dry-off management in preventing mastitis in dairy cows and the main preventive strategies that can be applied during this period.
Keywords: Dairy cattle, Mastitis, Dry period, Udder health

INTRODUCTION
Mastitis is a major health problem in dairy farms that reduces milk yield and quality, increases treatment and labour costs, results in discarded milk, and can lead to premature culling. In mastitis control, management practices during lactation and the dry period are both relevant. The dry period is an integral component of mastitis control programs, and infection risk increases, especially at the start of the dry period and near calving (Cengiz, 2009; Baştan and Cengiz, 2010; Kurt et al., 2019). Mastitis is inflammation of the mammary gland, most commonly associated with intramammary infection by pathogenic microorganisms. Mastitis causes significant economic losses at the herd level by disrupting mammary tissue function and negatively affecting milk quantity and composition (Sugimoto et al., 2006). Effective mastitis prevention depends on understanding pathogen transmission, infection risk, and appropriate herd-management practices.
Mastitis pathogens include *Streptococcus agalactiae*, *Staphylococcus aureus*, *Streptococcus dysgalactiae*, *Escherichia coli*, *Klebsiella* spp., *Streptococcus uberis*, and some enterococci (Bray and Shearer, 2003). Contagious mastitis pathogens are generally found on teat skin and in the mammary gland and can spread from animal to animal, especially during milking (Erdem and Atasever, 2004). Exposure to environmental mastitis pathogens occurs mainly through manure, bedding, soil, and water (Kul et al., 2008).
Intramammary infections may be described as latent, subclinical, or clinical (Atasever, 2007). In latent infection, there are no signs of inflammation and no pathological abnormality can be observed in the udder or milk. In subclinical mastitis, somatic cell count is typically elevated and pathogenic microorganisms may be present, but visible clinical signs are absent; some cases may subsequently become clinical. In clinical mastitis, the udder may be swollen, warm, painful, or reddened, and visible abnormalities such as flakes or clots may occur in the milk. Mastitis is generally associated with reduced milk yield (Windig et al., 2005; Kul et al., 2008).

Infections acquired during the dry period can manifest as clinical mastitis after calving, increasing the importance of preventive management during this period (Green et al., 2002).

The dry period refers to the nonlactating interval between the final milking at dry-off and the subsequent calving. During this process, the mammary gland transitions from active lactation to involution and then begins synthesizing colostrum in preparation for the next lactation. Because of anatomical, cellular, and immune-related changes in mammary tissue, susceptibility to new intramammary infections may increase, especially in the early and late phases of the dry period (Bradley and Green, 2004). Because infections acquired during the dry period can manifest as clinical mastitis after calving, preventive management during this period is especially important (Green et al., 2002). Factors such as body condition at dry-off, milk yield, previous udder-health status, and parity should be taken into consideration when planning dry-period herd management (Waldner, 2007).

The dry period in dairy cattle is an important period between two lactations in which mammary tissue undergoes structural and functional changes (Jánosi and Huszenicza, 2001). This period is important for mammary gland involution and renewal of secretory epithelial cells (Jones, 1998), as well as for supporting secretory function in the subsequent lactation (Jánosi and Huszenicza, 2001).

Jones (1998) recommended a dry period of approximately 60 days for dairy cows. Waldner (2007) suggested that a dry period of approximately 45–60 days is generally appropriate and reported that substantially shorter or longer dry periods may reduce milk yield in the subsequent lactation. Dry-period length should therefore be selected with consideration of subsequent production, health, and herd-management outcomes (Enevoldsen and Sørensen, 1992; Kul et al., 2008).

A substantial proportion of clinical mastitis cases in early lactation originate from infections acquired during the dry period (Eberhart, 1986; Green et al., 2001). Successful dry-period practices can reduce infection by 80% (Berry and Hillerton, 2002). The dry period may provide more favourable conditions for mastitis treatment than the lactation period. Not milking during this period allows antibiotics to remain effective in mammary tissue for longer, and long-acting intramammary formulations can maintain therapeutic concentrations for an extended period. In addition, more time for treated mammary tissue to heal helps reduce the risk of new infections and recurrence of clinical mastitis. Also, because milk is not offered for consumption, treatment occurs during a non-saleable milk period, although labelled withdrawal times must still be observed after calving (Jones, 1998; Waldner, 2007).

Successful dry-period management has two main purposes: curing existing intramammary infections at the end of lactation and preventing new infections from occurring during the dry period. Current dry-period management extends beyond antibiotic administration and includes somatic cell count (SCC), clinical mastitis records, internal teat sealants, dry-off strategy, housing hygiene, and feeding management (McMullen et al., 2021; McCubbin et al., 2022).

DRY-OFF MANAGEMENT

The conventional dry period is approximately 6–8 weeks. Shortening the dry period may reduce milk yield in the next lactation and provide some metabolic advantages. Van Knegsel et al. (2013) reported that shortening the dry period did not significantly change the risk of mastitis and that evidence for possible benefits to health and fertility was limited. Dry-period length should therefore be planned with consideration of milk yield, parity, body condition, and herd management.

The early dry period begins immediately after dry-off. During this phase, mammary gland involution and incomplete teat-canal closure can increase susceptibility to new intramammary infection (Bradley and Green, 2004). One main factor to consider at dry-off is milk yield at the last milking. In cows with high milk yield at dry-off, intramammary pressure and milk leakage may increase, involution may be delayed, and the risk of new infections increases. Vilar and Rajala-Schultz (2020) suggested a daily milk yield of approximately 15 kg or less at dry-off as an appropriate target. They reported that gradual milk cessation may help reduce milk leakage, intramammary pressure, and discomfort.

In high-yielding cows, milk yield should be reduced before dry-off through an appropriate milk-cessation strategy, and udder quarters should be examined for swelling or other signs of mastitis (Waldner, 2007). At dry-off, clean each teat with an alcohol cloth before administering intramammary dry-cow antibiotic therapy, when indicated; teat ends should be allowed to dry before infusion, and post-dipping should be performed after treatment (Schroeder, 1997).

These practices for each udder quarter can help prevent new infections during the dry period (Yüksel et al., 2004) and reduce the risk of new streptococcal intramammary infections (Smith et al., 1985).
The final two weeks before calving are called the late dry period (Burgemeister, 2006). If early dry-period treatment has not been highly effective, heightened vigilance is required regarding new intramammary infections, particularly during the last two weeks of the dry period. The calving area (maternity pen) should be clean, dry, well ventilated, and provide access to fresh water and feed; to this end, clean and disinfect the calving pen 1 to 2 weeks before the expected calving date (Waldner, 2007). Regardless of bedding type, maternity pens should be kept clean and dry because wet and contaminated bedding promotes bacterial growth and increases teat exposure to environmental mastitis pathogens (Jones, 1998; Uslucan and Özkütük, 2007). Additionally, separating close-up cows from the rest of the herd and moving them to a dedicated calving area one week before calving can be considered a management measure for reducing mastitis risk.

DRY PERIOD HERD MANAGEMENT

Dry Cow Antibiotic Therapy

Dry cow antibiotic therapy has historically been used to cure existing intramammary infections and, depending on the treatment strategy, to prevent new infections during the dry period. Long-acting intramammary formulations can maintain therapeutic concentrations during the nonlactating period, while saleable milk is not being collected; however, labelled withdrawal periods must be observed after calving (Jánosi and Huszenicza, 2001).
Dry cow antibiotic therapy is administered after the final milking at dry-off. Its two principal objectives are to cure existing intramammary infections and, depending on the treatment strategy, to prevent new infections during the dry period (Eberhart, 1986; Bradley and Green, 2001).
Two distinct approaches are commonly employed for dry cow therapy: “blanket dry cow therapy (BDCT)” and “selective dry cow therapy (SDCT).” In blanket dry cow therapy, long-acting intramammary antibiotics are administered to all udder quarters of every cow in the herd at dry-off, regardless of infection status. For many years, this approach provided significant benefits in treating existing infections, particularly in herds with a high prevalence of intramammary infections. However, improvements in herd udder health and growing concerns about antimicrobial resistance have led to a re-evaluation of routine antibiotic administration to healthy animals (McCubbin et al., 2022). In contrast, selective dry cow therapy involves administering antibiotics only to cows deemed to be infected or at high risk of infection. Decision algorithms using clinical mastitis records from the most recent lactation, individual SCC records, bacteriological culture results, or combinations of these criteria can be used to select cows for treatment. Cameron et al. (2014) evaluated the feasibility of implementing selective treatment decisions based on on-farm culture results in cows with low SCC. These findings indicate that selective treatment depends on reliable diagnostic information and accurate herd records. Kabera et al. (2021) reported that selective dry cow therapy (SDCT) could reduce antibiotic use by approximately 66% and that udder health was not adversely affected when internal teat sealants were used in cows classified as uninfected. Similarly, Rowe et al. (2023) and Paiva et al. (2024) showed that SDCT could be implemented successfully in suitable herds while reducing antibiotic use. Niemi et al. (2025) also indicated that this approach could be used to manage existing and new infections in herds managed with automatic milking systems.
However, SDCT should not be implemented in the same manner across all farms. Factors such as somatic cell count, mastitis history, herd records, and hygiene conditions must be considered, and antibiotic administration strategies should be tailored to the farm's udder-health status, records, and management conditions.
The efficacy of different antimicrobial compounds and routes of administration has also been investigated in dry-period therapy (Musal, 2000). Williamson et al. (1995) reported that dry-cow antibiotic treatment of uninfected quarters reduced new *Streptococcus uberis* infections from 12.3% in untreated quarters to 1.2% in treated quarters. Similarly, Nickerson et al. (1999) found that intramammary antibiotic administration against *Staphylococcus aureus* mastitis achieved success rates of 64.3% in cows and 78.1% in udder quarters. Dingwell et al. (2003) determined that intramammary antibiotic administration at dry-off yielded success rates of 67.3% in cows and 72.5% in udder quarters against *Staphylococcus aureus* throughout the dry period.

Another study found that administering the *E. coli* J5 vaccine 30 days before calving reduced the risk of coliform mastitis caused by environmental pathogens such as *E. coli* by 70–80% (Jánosi and Huszenicza, 2001). Despite the positive results observed in these studies, avoiding excessive antibiotic use and limiting administration to infected cows or quarters-thereby minimizing unnecessary antimicrobial exposure-is considered a rational approach (Kul et al., 2008).

Nutrition

Dry cows should receive a balanced ration that meets maintenance and pregnancy requirements while avoiding excessive energy intake and body-condition gain. There are four primary objectives regarding the nutrition of cows during the dry period and the three weeks before calving (Waldner, 2007; Kul et al., 2008):

- Providing adequate effective fibre
- Avoiding excessive energy intake
- Providing adequate, but not excessive, protein
- Meeting mineral and vitamin requirements

Dry-period nutrition should maintain appropriate body condition and prepare cows metabolically for the subsequent lactation. To this end, regularly assess the body condition of dry cows and implement a structured feeding program based on body condition scores to prevent condition loss or excessive fat accumulation (Tapkı et al., 2005). An increase in body condition score of between 0.25 and 0.50 points (on a 0-5 scale) during the dry period is undesirable (Waldner, 2007). Since mastitis problems are frequently observed in excessively fat cows (score >4) or in very poor condition (score <3) (Tapkı et al., 2005), it is recommended that cows maintain a body condition score between 3.0 and 3.5 during the dry period and at calving (Windig et al., 2005).

Adequate vitamin and trace-mineral nutrition is relevant to immune function in dry cows. Vitamin E deficiency reduces resistance to mastitis (Waldner, 2007), as vitamin E and selenium contribute to antioxidant defence and membrane protection (Dabak et al., 2002). Tjoelker et al. (1989) evaluated the effects of vitamin A and β-carotene on leukocyte and lymphocyte function during the early dry period. Weiss et al. (1997) found that supplementing the diet with 4000 IU/day of vitamin E during the final 14 days of the dry period reduced the risk of clinical mastitis in cows by 88%. Smith et al. (1984) reported that, compared with a control group, administering vitamin E, selenium, or a combination of both reduced the duration of clinical symptoms by 44%, 46%, and 62%, respectively. Scaletti et al. (2003) also emphasized that dietary copper supplementation during this period reduced clinical mastitis caused by *E. coli* bacteria, and that feeds rich in vitamin E and selenium reduced the overall risk of mastitis. During the dry period, animals should consume roughage amounting to at least 1% of their body weight, without exceeding 1% of their body weight in total feed intake (Şimşek & Aksakal, 2005), and excessive intake of Ca, P, Na, and salt must be avoided (Özen, 1999). Furthermore, during the eighth month of pregnancy, cows should be fed as if they were producing 5 litres of milk, and during the ninth month, as if producing 10 litres (Akman, 1998).

Husbandry Conditions and Environment

Dry-period herd management is directly relevant to mastitis prevention because poor environmental and hygiene conditions increase exposure to mastitis pathogens. In particular, if cows are housed in muddy, dirty environments and their udders are kept wet and soiled-especially around the time of calving—the risk of mastitis increases because teat ends are exposed to higher environmental bacterial loads (Schroeder, 1997; Kul et al., 2008). Indeed, Bradley and Green (2000) reported that herd-management factors during the dry period influence the incidence of coliform mastitis in subsequent lactations.

The keratin structure that develops within the teat canal during the dry period acts as a natural physical barrier against the entry of microorganisms into the udder. However, this barrier does not form at the same rate or with the same effectiveness in every cow. Internal teat sealants containing bismuth subnitrate were developed to support this natural barrier by physically sealing the teat canal. Berry and Hillerton (2002) showed that an antibiotic-free internal teat sealant could effectively prevent new intramammary infections. Crispie et al. (2004) also evaluated this approach as a non-antibiotic protection option, particularly for animals with low SCC that are considered uninfected at dry-off. When applying internal sealants, thoroughly clean the teat end before application and follow aseptic technique.

Introducing microorganisms into the teat canal during application can turn a procedure intended to be protective into a source of new infection (Schipper et al., 2025).

To protect dry cows from the sun, provide adequate shade and drainage. Keep animals away from dirty, damp, or muddy barns, loafing areas, pastures, and manure heaps as much as possible, since these environments expose teats to high bacterial loads and can lead to infections. Factors such as a lack of trees in pastures, overgrazing, and heavy rainfall promote infection; therefore, ensuring proper drainage and planting trees in these areas is beneficial. Because decaying feed accumulated during warm seasons or flies around manure heaps may increase exposure of teat ends to mastitis-causing bacteria, implement diligent fly-control measures (Jones, 1998). Consequently, it is particularly important to house dry cows in environments that offer optimal living conditions, specifically air temperatures between 0-15°C, humidity levels of 60-70%, and wind speeds ranging from 5-8 km/h (Kumlu, 1999).

CONCLUSION

Mastitis is an inflammatory disease of the mammary gland and a major udder-health problem in dairy cattle. Therefore, it is essential to thoroughly understand the factors contributing to mastitis and implement the necessary preventive measures in dairy herds. Poor herd-management practices-particularly regarding cows in the dry period-can lead to new infections during the subsequent lactation. Consequently, it is recommended to provide dry, clean housing and a suitable environment for dry cows, assess nutritional requirements and prepare fully balanced rations accordingly, and apply dry cow therapy according to infection status, herd records, and veterinary guidance. Regarding antibiotic administration, there is growing emphasis on making decisions based on the herd's specific udder-health status rather than applying a uniform approach to all herds. A selective dry-cow therapy approach-combining the use of internal teat sealants with the targeted use of antibiotics-can help reduce unnecessary antibiotic use in cows that have low SCC, no history of clinical mastitis, and are considered uninfected. Conversely, appropriate antibiotic treatment remains crucial for infected or high-risk animals. Appropriate dry-period management may reduce mastitis risk and associated production losses while supporting udder health in the subsequent lactation.

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WASTE HEAT RECOVERY TECHNOLOGIES FOR ENERGY-EFFICIENT AND DECARBONIZED MARINE VESSELS: A REVIEW

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ABSTRACT
Increasingly stringent emission regulations introduced by the International Maritime Organization (IMO) are compelling the maritime sector to improve the energy efficiency and environmental performance of commercial vessels. Marine diesel engines reject a substantial fraction of the supplied fuel energy through exhaust gases, cooling systems, and other heat losses, providing significant opportunities for waste heat recovery (WHR). This review provides an overview of current and emerging WHR technologies for improving the energy efficiency and supporting the decarbonization of marine vessels. Recent works examining WHR applications for different marine propulsion systems and ship types are explored with particular emphasis on their energy recovery potential, technological maturity, and practical applicability.
First, WHR systems based on thermodynamic power cycles, including the Rankine, Organic Rankine, Supercritical Rankine, and Kalina cycles, are reviewed together with their major configurations. Subsequently, exhaust gas turbine-based recovery systems, including turbo-compounding and hybrid turbocharger configurations, are examined. Finally, the potential of thermoelectric generators for direct conversion of waste heat into electrical power is discussed. The reviewed studies indicate that several WHR technologies have reached a relatively high level of technological maturity for maritime applications and can contribute to improved overall plant efficiency and reduced fuel consumption. However, widespread implementation remains constrained by installation and investment costs, variable operating conditions, system integration requirements, and exhaust thermal management. Despite the increasing adoption of alternative fuels and renewable energy technologies, internal-combustion-based propulsion systems are expected to remain an important component of the commercial fleet during the transition toward low-carbon shipping. Accordingly, WHR technologies can play a significant role in improving the energy efficiency and reducing the environmental impact of marine vessels in the coming decades.
Keywords: Waste Heat Recovery, Thermodynamic Power Cycles, Marine Vessels, Energy Efficiency, Decarbonization

INTRODUCTION
Nowadays, maritime transport plays an important role in global trade. Almost 90% of international trade is achieved through marine vessels and it is estimated that this trend is likely to continue in the short or medium term for the worldwide transportation of goods (Singh et al., 2023). Currently, marine diesel engines are the primary source for propulsion for most of the commercial ships. These power units are reliable, durable, have higher efficiency compared to gasoline engines and cost effective. Therefore, they are widely preferred for ship propulsion. However, diesel engines are also a source of high levels of carbon emissions into the environment, which is a significant threat for their use in marine vessels. Considering the strict plan of International Maritime Organization (IMO) for the reduction of Green House Gases (GHG) due to ships in the coming decade, some advanced techniques should be developed to improve the pollutant emissions of marine diesel engines to support the continued operation of maritime transport while meeting increasingly stringent environmental requirements (Bai et al., 2025).
It is seen from the literature that energy efficient vessels tend to have lower carbon monoxide (CO) and carbon dioxide (CO_2) emissions during their operations.

Wind assisted propulsion (WAP) has made significant progress for large vessels, solar power is tested for rather small vessels and alternative fuels such as methanol, hydrogen and liquefied natural gas are examined to enhance energy efficiency and limit the CO and CO_2 rates of ships (Ma et al., 2025). Those innovative technologies are effective to decrease energy consumption of ships. Particularly, new-built ships can be designed with such advanced technologies to further reduce carbon rates and meet IMO regulations. However, some challenges such as weather dependency of WAP, low power density of solar panels and issues regarding alternative fuel refueling, infrastructure, and engine equipment upgrades need to be overcome before their reliable application is maintained in ships (Başaran & Duranay, 2025).

Another effective and relatively mature method to improve energy efficiency in marine vessels is to apply waste heat recovery (WHR) for ships in operation. Some additional units can be installed at the outlet of the turbocharger to recover at least some percentage of the wasted heat (exhaust gas, air cooler, jacket water etc.) from the marine diesel engine system and produce added useful power in ships (Miller et al., 2024). While the WAP systems and solar panels utilize an outer power source to improve the ship propulsion, WHR systems use a power source (wasted heat), which is already lost from the fuel energy to the environment.

This work achieves a brief overview of current WHR systems implemented in marine vessels for the improvement of energy efficiency and engine-out emission rates. At first, technologies based on closed thermodynamic power cycles, namely Rankine cycle and Kalina cycle are explained. Secondly, turbo-compound systems with proper turbine configurations are explored. Lastly, the potential of thermoelectric generators for additional power production from waste heat is examined. The benefits and challenges of WHR systems are also analyzed and the study is concluded with some possible recommended future works for WHR application in ships.

MARINE WASTE HEAT SOURCES AND WHR PRINCIPLES

In a marine vessel, the energy source of marine diesel engine is the fuel energy (marine diesel oil, heavy fuel oil or marine gas oil). In such an engine system, only some percentage of that energy can be converted to useful propulsion power for the ship. The rest of the fuel energy is lost to the environment as wasted heat as in Figure 1 (MAN Diesel&Turbo, 2012).

Figure 1 indicates that more than 50% of the fuel energy (a significant portion) is dissipated without being converted into useful ship propulsion power. Among these losses, the energy discharged via radiation, lubrication oil, and jacket water accounts for a relatively small proportion, nearly 10% in total, and may be less attractive for major ship propulsion-power recovery. In contrast, the energy associated with the scavenge-air cooler and exhaust gas accounts for more than 40% of the fuel energy in total and thus, represents a considerable opportunity for WHR systems to produce additional useful power for the ship.

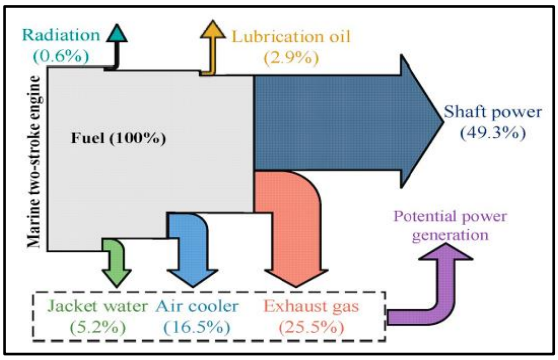


Figure 1. Energy balance diagram of a marine two-stroke engine (MAN 12K98 ME/ MC) operating at 100% SMCR (MAN Diesel&Turbo, 2012)

The quantity of wasted heat is essential for WHR units to provide sufficient power for the ship. However, the quality of the wasted heat, which depends on the temperature, is also significant to improve the efficiency of WHR systems. It is also important for heating exhaust after-treatment units and enhancing their effectiveness (Basaran & Ozsoysal, 2017; Başaran, 2024).

While the exhaust gas temperature remains mostly between 250-500ºC, the scavenge air temperature lies generally between 130-150ºC for a sea going vessel (Shu et al., 2013). The thermodynamic quality of a heat source increases with its temperature relative to the heat sink. Therefore, high-temperature exhaust gas generally offers greater power-generation potential, whereas lower-temperature sources may require appropriately selected cycles or combined recovery configurations (Singh & Pedersen, 2016).

The WHR system can be installed depending on a single heat source (such as engine-out exhaust gas or heat lost to air cooler) or depending on a combined heat source (exhaust gas + wasted heat through air cooler + wasted heat through jacket cooling) in a marine vessel. However, the selected WHR technology should primarily consider the temperature and thus, the quality of the heat source in order to maintain the high effective performance on board. Moreover, the reliability and safety of the technology, its durability, its ability to control different heat source and sink properties for transient vessel operations at sea and its smooth integration with adjacent engine units are other significant parameters before a practical WHR system is installed on a ship.

MAIN WHR TECHNOLOGIES

Rankine Cycle – Based Systems

One of the effective WHR techniques is to implement a Rankine cycle – based unit at the outlet of the turbocharger in a marine vessel. In a basic Rankine cycle system, there are four main components: a boiler, a turbine, a condenser and a feed-pump. The boiler, or evaporator in some WHR configurations, transfers heat from the exhaust gas to the working fluid and produces vapor. The hot exhaust gas flowing at the outlet of the turbocharger is used as the heat source to obtain vapor in the boiler. The vapor is directed to the turbine to expand through spinning of the turbine blades and thus, additional rotational work is produced for the marine vessel. Then, the expanded vapor flows through the condenser and cools off through transferring heat to the sea water. Finally, the cooled working fluid enters the feed-pump and is pumped to the boiler, where it is heated again to generate vapor for the turbine and continue producing useful rotational work.

A typical schematic of Rankine cycle is illustrated in Figure 2 (Reddy et al., 2010). As the working fluid in the cycle is specified as water (steam), then it is called as steam Rankine cycle (SRC). Instead of steam, when the working fluid is determined as an organic fluid (hydrocarbon gases or refrigerants such as R134a, R245fa etc.), then the cycle is named as organic Rankine cycle (ORC).

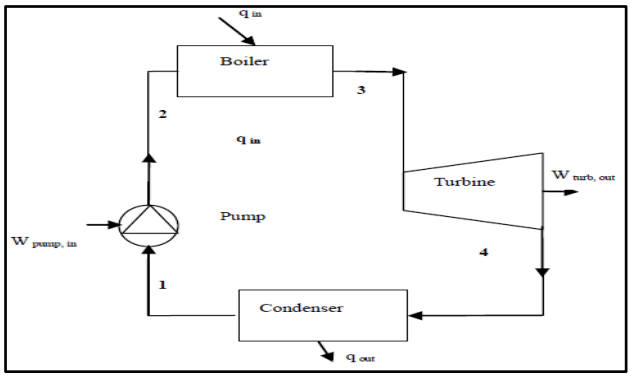


Figure 2. A simple schematic of a Rankine cycle system (Reddy et al., 2010)

SRC systems have been in use for a very long time and thus, are reliable to produce additional power in onshore or marine vessels. Medium temperature sources such as the exhaust heat in a marine diesel engine system is ideal to provide additional power and improve fuel savings in a ship. ORC systems have a similar layout to that of a SRC unit. However, they can be advantageous compared to SRC systems as the specific vaporization heat of the working fluid (water is replaced with a proper organic fluid) mostly remains at a lower level compared to water (Konur et al., 2022). With a suitable organic fluid selection, ORC systems can be planned to perform both for low & medium quality waste heat in a ship.

In addition to SRC & ORC, supercritical Rankine cycle (SCRC) can be applied as an effective WHR system. Different from SRC & ORC, in which the working fluid passes through a two-phase process (liquid + vapor) in the boiler, in an SCRC system, the pressure of the working fluid is increased above the critical pressure in the pump and as it is heated, it directly passes from liquid to vapor phase, bypassing the liquid-vapor mixture process. By operating above the critical pressure, the working fluid is heated without undergoing conventional two-phase boiling. This can improve the temperature match between the heat source and the working fluid and may reduce irreversibilities in the heat-addition process (Schuster et al., 2010). The resulting performance advantage depends on the working fluid, operating conditions and system configuration. Moreover, unlike an SRC system, where the working fluid can remain at liquid-vapor mixture state at the outlet of the turbine, in an SCRC system, the working fluid generally remains at vapor phase at the end of the expansion process as it enters the turbine at much higher temperature. Thus, turbine blade erosion risk can be lowered in such a system.

Kalina Cycle – Based Systems

Another effective WHR technology is to apply a Kalina cycle (KC) system at the downstream of the turbocharger in a ship. In this power cycle system, ammonia-water mixture is utilized as the working fluid, unlike aforementioned RC systems in which only water or organic fluid is used as the working fluid. The advantage of a KC system is that during heat transfer processes in the cycle, as seen in Figure 3, the temperature does not remain constant (Singh & Pedersen, 2016).

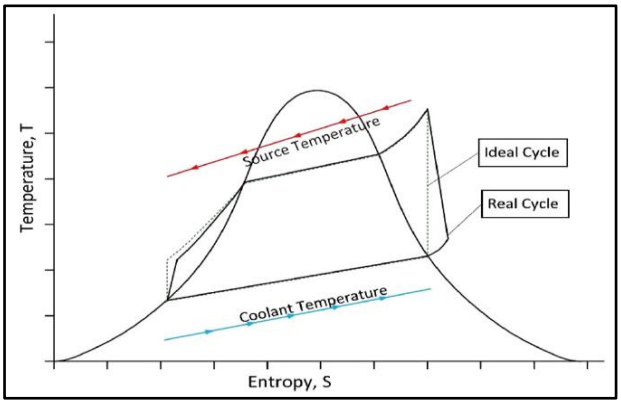


Figure 3. Variable temperature boiling/condensation in a KC system (Singh & Pedersen, 2016)

Different from RC systems, where the working fluid temperature is constant during evaporation or condensation, the mixture temperature in KC system increases during heat gain and decreases during heat loss. Therefore, KC has a better thermal match with heat source and heat sink in comparison to RC systems. The efficiency of the boiler can be increased and the average temperature at condenser can be decreased in KC; thus, the overall thermal efficiency of the cycle can be improved.

KC systems can be more practical for waste heat source at low temperature compared to RC and ORC systems. The use of an ammonia–water mixture in KC systems provides thermodynamic flexibility, but ammonia toxicity, containment, leakage prevention and safety requirements must be considered in marine applications. Furthermore, depending on the design and operating conditions, Kalina systems may offer compact configurations, although their separators, recuperators, control requirements and working-fluid management can increase system complexity (Zhang et al., 2012). Therefore, this can be an advantage for a marine vessel with limited space for the installation of a large WHR unit.

Exhaust-Gas Turbine and Turbo-Compounding Systems

In addition to aforementioned thermodynamic power cycles, an additional exhaust gas turbine (generally called power turbine) can be placed at the outlet of the exhaust unit in a marine diesel engine system to obtain extra useful power. This process is generally known as “turbo-compounding”, and systems of this type that utilize an independent power turbine (PT) to extract additional power from waste heat are referred to as turbo-compound systems (TCS). The most common types of turbo-compounding for WHR are mechanical, hydraulic and electrical TCS. A typical mechanical TCS is demonstrated in Figure 4 (Dieselnet, 2020).

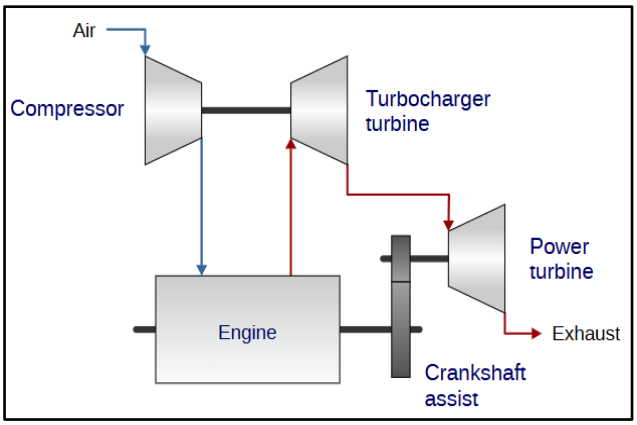


Figure 4. Schematic of a mechanical turbo-compound system (Dieselnet, 2020)

In a mechanical TCS, as in Figure 4, the exhaust gas at the downstream of the turbocharger turbine is directed to the PT unit. It is expanded in this particular turbine and then released to the environment. The additional power produced through this expansion process is fed to the main engine shaft via a mechanical connection (mostly via a reduction gearbox); hence, it is referred to as mechanical turbo-compounding. The reduction gearbox behaves as a coupler between the power-turbine shaft and the main engine shaft. Since the rotational speed of the power-turbine shaft is much higher than that of the main engine shaft, in most cases, a speed regulating mechanism is utilized to transfer the additional power to the main engine shaft in a reliable manner.

Different from a mechanical TCS, a hydraulic TCS transmits the additional power obtained from the turbine to the main engine shaft through a hydraulic system. Mostly, a high-speed hydraulic pump and a low-speed hydraulic motor are utilized to transfer the turbine power to the main shaft of the system. In such a system, the turbine is connected to the hydraulic pump and it increases the pressure of the fluid inside its hydraulic circuit. Then, this high-pressure fluid drives the hydraulic motor, which is linked to the main shaft or a generator in the system. A speed controller adjusts the speed of the hydraulic motor and the speed of the engine shaft to maintain the transfer of power in a secure manner.

Another effective turbo-compounding technology is the electrical TCS. It is known as “turbo-generator system” as well. Similar to a mechanical TCS, electrical TCS also uses a PT to extract additional power from the wasted exhaust heat. However, in this system, the PT is directly connected to a generator, instead of being connected to main engine shaft as in mechanical TCS (Aghaali & Ångström, 2015). Therefore, the additional mechanical power through PT is not transmitted directly to the engine shaft, but converted to electrical power via a generator and can be used to meet any power need. Since there are less mechanical connections compared to mechanical TCS, turbo-generators generally have lower mechanical loss and can perform more efficiently than mechanical TCS. However, it is noted that turbo-generators still suffer from generator efficiency and transmission losses and thus, the turbine power cannot be completely converted to electrical power in those systems.

A related configuration is the hybrid turbocharger, in which a motor-generator is integrated with the turbocharger shaft. Depending on the operating condition, the electrical machine can recover surplus turbocharger power or provide assistance to the turbocharger compressor. This arrangement can improve turbocharger flexibility, support engine operation during transient conditions and generate additional electrical power (Shiraishi et al., 2010). Its practical benefits depend on the electrical architecture, control strategy, engine operating profile and available exhaust-gas energy.

Thermoelectric Generation Systems

The last category of WHR technologies is the thermoelectric generation (TEG). This technology depends on the ‘Seebeck Effect’, in which a temperature difference between two different conductors connected with each other generates a voltage difference between the two components. A simple, general schematic of a TEG unit is illustrated in Figure 5 (Saha et al., 2023).

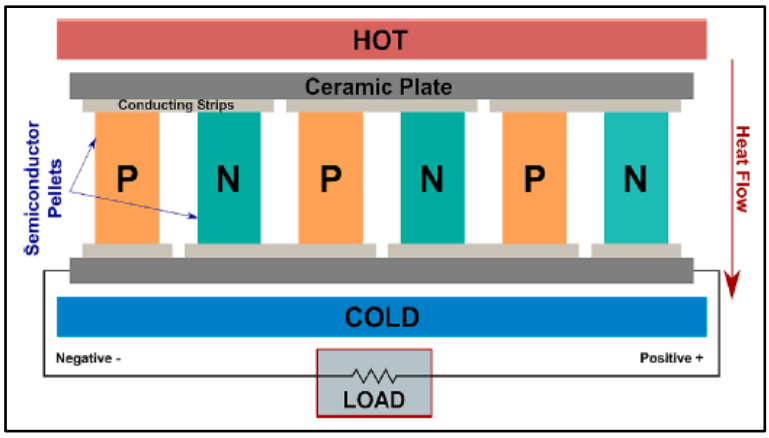


Figure 5. General schematic of a simple TEG system (Saha et al., 2023)

Waste heat source (hot fluid) is used to maintain the hot junction of the module in Figure 5 at relatively high levels. In a similar manner, the heat is released to a low temperature sink (cold fluid) to secure the cold junction of the module at low temperatures. As long as a certain temperature gradient is maintained between the junctions, electron charge is carried from the hot junction to the cold junction through thermoelectric material and a voltage is produced in the system.

The effectiveness of a TEG system is based on the temperature difference between the junctions (hot and cold), electric current and the type and characteristics of conductors/semiconductors used in the system. Thermoelectric modules can be connected either in parallel or in series to achieve the amount of current or voltage demanded by the system.

One advantage of a TEG system is that, unlike previous WHR technologies, it does not include any moving parts. Therefore, it can operate very quietly on ships without causing any undesirable high noise levels or any significant vibrations. Another benefit of TEG is that it is fully scalable and can be designed to meet various needs. Also, these systems are mostly found to be durable and reliable for long-term use. However, reported conversion efficiencies for practical TEG applications are generally modest and depend strongly on the temperature gradient, thermoelectric material, module design and heat-transfer conditions (Kristiansen et al., 2012). Thus, further development on material characteristics and TEG design is required to improve the recovery efficiency and maintain practical application of TEG units in marine vessels (Zoui et al., 2020).

BENEFITS AND CHALLENGES OF WHR SYSTEMS

Benefits

WHR systems can provide additional shaft power, electrical power or useful thermal energy, depending on their configuration in the marine vessel. There is no extra fuel consumption requirement in this waste recovery process so that more power is obtained with a similar fuel consumption. Since the carbon emission of a ship is directly related to total fuel/energy consumption, the fuel efficiency gained via WHR units is beneficial to reduce particularly CO_2 rates as well. Moreover, lower fuel consumption of the vessel results in reduced fuel cost, which can be advantageous to decrease total operation cost of the ships.

Current IMO regulations demand a considerable reduction in carbon rates of all marine vessels. Utilizing WHR systems can enable fuel efficient propulsion and decreased carbon rates due to ships. Therefore, installation of WHR systems in ships can be a proper solution to meet strict IMO regulations.

Several WHR technologies, particularly steam-based systems and exhaust-gas power-recovery configurations, have reached relatively high technological maturity in marine and related applications. They have mostly improved maturity compared to alternative fuel-based, wind-assisted or solar-assisted propulsion. WHR may therefore remain useful and practical in ships to improve fuel efficiency and decarbonization during the transition toward lower-carbon and increasingly electrified marine propulsion systems.

Challenges

One important challenge of a WHR system is the requirement of the initial investment of the equipment by the shipowner. The increased cost is highly undesirable. However, fuel consumption improvement due to WHR system can significantly lower the annual fuel cost of the vessel. Therefore, payback period of the installation cost can be reduced and using WHR units in ships can be more desirable. In addition to installation cost, a WHR unit has to adapt transient operations of the ship. The effectiveness of the WHR system can vary due to low steaming, change of seawater temperatures and change of route and weather conditions. Therefore, a WHR system needs to rapidly adjust its operation to maximize its power assistance considering aforementioned transient conditions of a marine vessel.

Another significant challenge for WHR systems is the space requirement in engine room. Considering the piping, connections, reduction gear unit, main and auxiliary diesel engine systems, the engine room of a marine vessel is already a highly complex area. Placing an additional equipment into such a complicated area requires a significant plan. For newbuild ships, the space requirement for a WHR system can be considered at the early stages of the design. Therefore, a specific and separate area can be allocated for the WHR unit, and its installation can be relatively more practical. However, for ships already in service, an extensive retrofitting process may often be required to secure a suitable space in the engine room. This undertaking can be both technically challenging and costly for the shipowners.

It is noted that WHR systems need periodic maintenance to maintain their effective performance in ships, which can increase the operation cost. Also, their integration and compatible operation with other propulsion units should be considered before they are fully installed in a commercial vessel.

CONCLUSIONS

This paper has presented a concise review of the principal waste heat recovery (WHR) technologies applicable to marine vessels, with emphasis on their operating principles, energy recovery potential, technological maturity and practical implementation requirements. Marine diesel engines reject a considerable portion of the supplied fuel energy through exhaust gases, air-cooling systems, jacket-water systems and other heat-loss mechanisms. These energy streams provide opportunities to improve overall propulsion-system efficiency by producing additional shaft power, electrical power or useful thermal energy.

The reviewed technologies include steam Rankine, Organic Rankine and supercritical Rankine cycles, Kalina-cycle systems, exhaust-gas turbine and turbo-compounding configurations, and thermoelectric generators. Rankine-based systems and turbo-compounding technologies offer relatively high technological maturity and have considerable potential for marine applications. ORC and Kalina systems may provide advantages when medium- or lower-temperature heat sources are available, although their performance depends strongly on working-fluid selection and system configuration. TEG systems offer compactness and the absence of moving parts, but their relatively low conversion efficiency remains an important limitation.

Despite those advantages, the practical implementation of WHR systems is affected by initial investment, payback period, variable engine-load conditions, limited engine-room space, maintenance requirements and integration with existing propulsion and exhaust systems. Therefore, the optimum WHR solution cannot be determined independently of the vessel type, engine characteristics, operating profile and available heat sources. Further research should focus on reliable off-design operation, hybrid WHR configurations, control strategies and techno-economic assessment for different marine applications. Overall, WHR remains a valuable energy-efficiency option for reducing fuel consumption and supporting the transition toward lower-carbon shipping.

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EFFECTS OF GERMINATION ON AROMA PROFILE AND AROMA-ACTIVE COMPOUNDS IN CEREALS AND LEGUMES: A REVIEW

TAHIL VE BAKLAGİLLERDE ÇİMLENDİRMENİN AROMA PROFİLİ VE AROMA-AKTİF BİLEŞİKLER ÜZERİNDEKİ ETKİLERİ: BİR DERLEME

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ABSTRACT
Legumes and cereals are among the nutritious, low-cost, and sustainable food sources; their use in the food industry is expanding with the increasing interest in plant-based nutrition. However, the raw forms of these products contain antinutritional components such as phytic acid and tannins, and have some limitations in terms of nutritional bioavailability. Germination, a low-cost and environmentally friendly pretreatment, stands out as an effective method to overcome these limitations due to its potential to improve nutritional quality and reduce antinutritional factors. At the same time, in this process, the volatile compound profile of the seed, especially in terms of aroma-active compounds, changes, directly affecting the aroma and flavor characteristics of the product. In this review, the changes in aroma profile and aroma-active compounds caused by the germination process in various cereals and legumes are evaluated in light of the current literature; the main biochemical mechanisms underlying these changes, such as lipid oxidation, protein/amino acid degradation, and carotenoid degradation, and the analytical methods used to determine these compounds are discussed comparatively. The studies reviewed show that germination triggers the formation of pleasant fruity, floral, and nutty aroma compounds in many products, but can also lead to the emergence of compounds associated with undesirable beany, earthy, and herbaceous notes. It has been determined that this effect varies depending on the type and variety of the germinated product, and especially the germination time. These findings highlight the importance of optimizing germination conditions on a product-specific basis to achieve the targeted aroma profile in food applications.
Keywords: Germination, aroma, aroma-active compounds, olfactometry.

ÖZET
Baklagiller ve tahıllar, besin değeri yüksek, düşük maliyetli ve sürdürülebilir gıda kaynakları arasında yer almakta; bitkisel bazlı beslenmeye yönelik artan ilgiyle birlikte gıda sanayisindeki kullanım alanları da giderek genişlemektedir. Bununla birlikte, bu ürünlerin ham hâlleri fitik asit ve tanen gibi antibesinsel bileşenler içermekte ve besin biyoyararlanımı bakımından bazı sınırlılıklar taşımaktadır. Düşük maliyetli ve çevre dostu bir ön işlem olan çimlendirme, besin kalitesini artırma ve antibesinsel faktörleri azaltma potansiyeliyle bu sınırlılıkların giderilmesinde etkili bir yöntem olarak öne çıkmaktadır. Bununla birlikte bu süreçte tohumun uçucu bileşik profili, özellikle aroma-aktif bileşikler bakımından değişerek ürünün aroma ve lezzet karakterini doğrudan etkilemektedir. Bu derlemede, çimlendirme işleminin çeşitli tahıl ve baklagillerde meydana getirdiği aroma profili ve aroma-aktif bileşiklerin değişimleri güncel literatür ışığında değerlendirilmiş; bu değişimlerin altında yatan lipit oksidasyonu, protein/amino asit degradasyonu ve karotenoid parçalanması gibi başlıca biyokimyasal mekanizmalar ile bu bileşiklerin belirlenmesinde kullanılan analitik yöntemler karşılaştırmalı olarak ele alınmıştır. İncelenen çalışmalar, çimlendirmenin birçok üründe hoş meyvemsi, çiçeksi ve fındıksı aroma bileşiklerinin oluşumunu tetiklediğini, ancak aynı zamanda istenmeyen fasülyemsi, topraksı ve otsu notalarla ilişkilendirilen bileşiklerin ortaya çıkmasına da yol açabildiğini göstermektedir. Bu etkinin çimlendirilen ürünün türüne, çeşidine ve özellikle çimlendirme süresine bağlı olarak değiştiği belirlenmiştir. Bu bulgular, gıda uygulamalarında hedeflenen aroma profilinin elde edilebilmesi için çimlendirme koşullarının ürüne özgü olarak optimize edilmesinin önemini ortaya koymaktadır.
Anahtar kelimeler: Çimlendirme, aroma, aroma-aktif bileşikler, olfaktometri.

INTRODUCTION

Legumes and cereals stand out as low-cost and sustainable food sources rich in protein, carbohydrates, dietary fiber, vitamins, and minerals in human nutrition (Wanniarachchi et al., 2026). Especially with the increasing interest in plant-based nutrition, the use of legumes such as chickpeas, mung beans, and lentils, as well as cereal/pseudo-cereal products such as quinoa and rice, is becoming increasingly widespread in the food industry. However, the unprocessed forms of these products have limiting characteristics including antinutritional components such as phytic acid and tannins, and low protein and mineral bioavailability (Thakur et al., 2020). Therefore, germination, a low-cost and environmentally friendly process in which seeds undergo biochemical and physiological changes by absorbing water under suitable moisture and temperature conditions, has become one of the widely applied pre-treatments in the food industry (Rahman et al., 2023). In the germination process, the seed is first moistened by absorbing water from the external environment; as a result, the respiration rate of the seed increases, and protein synthesis is triggered, restarting the metabolic activity of the seed. Furthermore, with water uptake, the structure of the seed coat changes, becoming more conducive to the passage of oxygen and water into the seed (Bera et al., 2023). This process stands out for its potential to improve nutritional quality, reduce anti-nutritional factors, and increase antioxidant capacity (Xu et al., 2019; Rajhi et al., 2022; Kılıç and Koyuncu, 2026). As a result, germinated products are increasingly preferred among consumers who prioritize healthy eating (Wang et al., 2026). In addition to nutritional and functional improvements during the germination process, the volatile compound profile of the seed also changes, and this change directly affects the aroma and flavor characteristics of the product (Thakur et al., 2020; Ritter et al., 2024). Indeed, the complex interaction of volatile and non-volatile compounds released during germination determines both odor and taste perception (Leonard et al., 2022).

The aroma changes caused by germination are fundamentally based on enzymatic systems activated by germination in the seed and the associated biochemical reactions (Rajhi et al., 2024). The aroma components of legumes generally originate from aldehyde, alcohol, ketone, and pyrazine derivatives (Xu et al., 2019; Rajhi et al., 2022), and it has been reported that multiple biochemical pathways, such as lipid oxidation, protein/amino acid degradation, and carotenoid degradation, play a role in the formation of these compounds (Wanniarachchi et al., 2026).

In this review, the combined evaluation of findings regarding aroma changes in different cereal and legume types due to germination is important for providing a holistic perspective on the subject. The aroma changes caused by germination in various cereals and legumes (beans, chickpeas, rice, etc.) have been reviewed based on recent studies; the main biochemical mechanisms underlying these changes and the analytical methods used have been discussed comparatively.

THE EFFECT of GERMINATION on AROMA COMPOUNDS

Aroma is one of the sensory elements that determine food quality, and it is among the factors that most influence consumer preference (Wang et al., 2026). Aroma compounds, called volatile organic compounds (VOCs), can easily diffuse into the environment at room temperature due to their low vapor pressure and are detected by olfactory receptors in the nasal cavity (Pu et al., 2025; Wanniarachchi et al., 2026). The smell of a food is not caused by a single aroma compound, but usually by the combined effect of hundreds of different volatile compounds (Al-Khalili et al., 2025). Although most of these compounds are found in extremely low concentrations (at the level of µg/kg-ng/kg), their effects on aroma perception are not always directly proportional to their concentrations (Peng et al., 2024).

Volatile compounds are generally determined by gas chromatography-mass spectrometry (GC-MS), but samples need to undergo an appropriate extraction process before this analysis. The main methods used for this purpose in the literature are: steam distillation, simultaneous distillation-extraction (SDE), dynamic headspace/purge-trap extraction, solid-phase microextraction (SPME), stir bar sorptive extraction (SBSE), liquid-liquid extraction, and solvent-assisted flavor evaporation (SAFE) (Pu et al., 2025; Al-Khalili et al., 2025). Applying high temperatures in steam distillation can lead to losses in some heat-sensitive compounds. Although the SDE method (Likens-Nickerson technique) performs distillation and extraction steps simultaneously, it has been reported that the resulting extract may not accurately reflect the true aroma profile of the sample, and thermolabile compounds may be lost in this process (Wanniarachchi et al., 2026).

In the dynamic headspace method, for example, a stream of inert gas (helium or nitrogen) passed over the sample transports volatile compounds to an adsorbent trap; the trapped compounds are then released by thermal desorption or with the help of a solvent (Al-Khalili et al., 2025). The preferred method in current studies on germinated cereal and legume aroma is headspace solid-phase microextraction (HS-SPME). In this technique, volatile compounds in the headspace of the sample are adsorbed onto a fiber coating, usually consisting of a mixture of Divinylbenzene/Carboxen/Polydimethylsiloxane (DVB/CAR/PDMS), and then the fiber is placed in a GC injection port to release the compounds by thermal desorption. Due to its solvent-free nature, speed, and relatively simple application, HS-SPME has become a popular choice in germination studies (Rajhi et al., 2024; Kılıç and Koyuncu, 2026; Wu et al., 2011; Peng et al., 2024). However, the fragile nature of the fibers necessitates careful handling (Xu et al., 2024). The SBSE technique also does not require a solvent; extraction is achieved by directly immersing a polydimethylsiloxane-coated magnetic stirring rod into the sample (Zhao et al., 2021). In the SAFE method, evaporation is carried out under low temperature (<50°C) and high vacuum conditions to protect heat-sensitive compounds (Song and Liu, 2018; Yang et al., 2025).

In cereals and legumes, these volatile compounds are classified according to their chemical structure into categories such as aldehydes, alcohols, ketones, esters, terpenes, furans, and nitrogen/sulfur-containing heterocyclic compounds, each contributing to the overall odor profile of the product to varying degrees (Wanniarachchi et al., 2026). The formation of these compounds is based on three main mechanisms reported in the literature: enzymatic lipid oxidation via lipoxygenase and lipase activity, degradation of amino acids (including the Maillard reaction and its associated Strecker degradation), and the breakdown of carotenoids (Leonard et al., 2022; Rajhi et al., 2024). During this amino acid degradation process, proteases activated by germination break down storage proteins into free amino acids and small peptides. These products then provide the substrates needed for the Maillard reaction and Strecker degradation, resulting in the formation of aroma compounds (Bera et al., 2023). Among these, the lipoxygenase pathway stands out in particular. This enzyme targets the 1,4-pentadiene structure in polyunsaturated fatty acids such as linoleic and linolenic acids, forming hydroperoxide intermediates; the breakdown of these products then yields short-chain aldehyde, ketone, alcohol, and furan derivatives (Wang et al., 2025; Wanniarachchi et al., 2026). In addition to these mechanisms, it has been suggested that the hydrolysis of starch and proteins by α-amylase and protease enzymes secreted during germination may release bean aroma compounds that are attached to these macronutrients via hydrogen bonds and hydrophobic interactions; this may indirectly contribute to the enhancement of aroma (Xu et al., 2019). One of the important consequences of these biochemical changes is the formation of undesirable (off-flavor) notes by some volatile compounds. Specifically, notes described as beany, herbaceous, green, and earthy are among the main factors limiting consumer acceptance of unprocessed legumes (Wanniarachchi et al., 2026). In this regard, a study by Xu et al. (2019) reported that germination increased the beany odor in lentils and yellow peas, decreased it in chickpeas, but resulted in other unpleasant odors. It has been reported that these bean-scented aroma compounds are generally formed during germination through lipolysis, lipid oxidation, and the breakdown of amino acids (Murat et al., 2013; Xu et al., 2019). Consequently, the extent to which germination reduces the formation of these undesirable aroma compounds or leads to the emergence of different pleasant aroma compounds varies in studies conducted on different cereal and legume types (Rajhi et al., 2024; Yang et al., 2025).

A previous study on brown rice used the HS-SPME/GC-MS method to apply a germination process lasting 1 to 5 days to three different rice varieties. It was reported that germination for 1 to 3 days increased desirable volatile compounds and reduced undesirable aroma compounds, improving flavor. However, it was noted that prolonged germination of 4-5 days led to an excessive increase in aldehyde, phenolic compound, and especially dimethyl sulfide content, resulting in an undesirable aroma profile (Wu et al., 2011). This finding highlights the need to optimize germination time.

In a study where different faba bean (*Vicia faba* L.) varieties were germinated for 5 days, the volatile compounds of germinated and ungerminated samples were examined using HS-SPME/GC-MS. A total of 37 different volatile compounds were detected, 28 in germinated samples and 19 in ungerminated (raw) samples. It was reported that the germination process led to the formation of oxygenated monoterpenes, an increase in non-terpene derivatives, and a general decrease in monoterpene hydrocarbons.

Furthermore, it was reported that germination of faba bean seeds resulted in a significant increase in aldehyde content and a decrease in esters. Nonanal was identified as a key marker of the bean odor, originating from fatty acid oxidation, and was commonly found in all faba bean samples (raw and germinated). While nonanal was found in low amounts in ungerminated samples, it increased 1.6-12.4 times after germination and became the dominant volatile component in most varieties. This increase was thought to be related to the rise in lipase activity and the acceleration of fatty acid oxidation during the germination process. The findings emphasized that germination, contrary to expectations, strengthens the undesirable bean odor, and that this effect may vary depending on the germination time and legume varieties (Rajhi et al., 2022).In the study conducted by Rajhi et al. (2024), the effects of 5 days of germination on volatile organic compounds in three different dry bean varieties (Navy, Kidney, Black) were investigated using the HS-SPME/GC-MS method. While the most dominant volatile classes varied depending on the variety in ungerminated samples, after 5 days of germination, non-terpene derivatives became the most dominant aroma group in all varieties, and nonanal rose to become the most dominant compound in all varieties. It was stated that germination reduced the total compound diversity; 40 compounds were detected in ungerminated samples, while this number decreased to 31 in germinated samples. In contrast, it was reported that germination significantly increased the proportion of aldehydes such as heptanal, benzaldehyde, and octanal, which are associated with undesirable bean/green odor notes and are not present in ungerminated samples, as well as new alcohol compounds, thus triggering negative aroma development in dry beans due to lipid peroxidation.

Similarly, in the study conducted by Kılıç and Koyuncu (2026), the effects of germination treatment applied for 48 hours on the aroma compounds of chickpea (*Cicer arietinum* L.) were investigated using the SPME-GC/MS method. It was reported that a total of 65 volatile compounds, including esters, aldehydes, alcohols, hydrocarbons, ketones, terpenes, acids, and other aroma compounds, were identified in chickpeas, and that the number of these volatile compounds increased with the germination process. While alcohols, esters, and terpenes were the most dominant volatile compound classes in ungerminated chickpea samples, after 48 hours of germination, esters became the most dominant aroma group by far, followed by alcohols and terpenes, respectively. It was reported that the germination process resulted in the formation of 19 new volatile compounds with fruity (pineapple, apple, pear) aroma notes, such as isoamyl butyrate, butanoic acid hexyl ester, and ethyl hexanoate. It has been reported that the germination process significantly increases the total volatile compound concentration due to lipoxygenase activity, but it also leads to the emergence of the compound 2-pentylfuran, which is not present in ungerminated chickpeas and is associated with an undesirable beany/earthy aroma.

THE EFFECT OF GERMINATION ON AROMA-ACTIVE COMPOUNDS

The chemical identification of a volatile compound does not necessarily mean that it contributes to the perceived aroma of food; even some compounds present at low concentrations can play a decisive role in aroma perception and are responsible for the characteristic odor of that food (Gou et al., 2021). These compounds are called aroma-active compounds. The characteristic odor of food depends on the combination of these aroma-active compounds, their concentration, and their odor perception threshold (Djebari et al., 2023). Gas chromatography-olfactometry (GC-O) and/or gas chromatography-mass spectrometry-olfactometry (GC-MS-O) techniques, in which the human sense of smell is used as a detector, are used in the identification of these compounds (Al-Khalili et al., 2025; Yang et al., 2025). One of the most common methods used to determine aroma-active compounds is aroma extract dilution analysis (AEDA). In this method, the obtained aroma extract is gradually diluted, and each diluted sample is evaluated by olfactometry to determine the highest flavor dilution (FD) factor at which each compound is still detectable (Al-Khalili et al., 2025). In a study by Xu et al. (2019) on different germinated legumes (chickpeas, lentils, and yellow peas), it was reported that 62 out of a total of 124 volatile compounds were identified as odor-active by GC-O. It was noted that germination resulted in an increase in green, grassy, cucumber-like, bean-like, earthy, and some undesirable (off-flavor) odors in all three legumes. It was reported that the odor profiles of ungerminated lentils and yellow peas were very similar, but this similarity decreased after germination. It has been reported that lentils acquire more floral (benzeneacetaldehyde), bean, and herbaceous aromas, while yellow peas acquire more plastic (nonanal), almond-like (benzaldehyde), and green aromas.

In chickpeas, pleasant aromas such as woody, clove-like, caramel, and floral aromas increase; however, strong undesirable odors such as acidic/sour (2-methylhexanoic acid), pungent/sweaty (octanoic acid), and fishy odor ((2-aziridinylethyl)amine) also appear.

The amount of a compound alone may not reflect its contribution to overall odor perception, as the odor threshold, the minimum concentration required for a compound to be detected, varies from compound to compound (Mishra et al., 2019). Therefore, the odor activity value (OAV), calculated by dividing the measured concentration of a compound by its odor threshold, has become an important indicator in identifying compounds that truly contribute to the aroma profile (Pu et al., 2025). In general, compounds with an OAV ≥ 1 are considered potential aroma-active compounds (Peng et al., 2024). In this regard, a study by Wang et al. (2025) investigated the effect of germinating brown rice (*Oryza sativa* L.) for different durations (0, 24, and 48 hours) on its aroma profile. GC-MS analysis detected a total of 364 volatile compounds in brown rice samples with varying germination times, with esters, heterocyclic compounds, hydrocarbons, and terpenoids being the most dominant compound groups. The researchers reported that the volatile compound profiles of the samples differed significantly after germination; 24 hours of germination increased many aroma-related volatile compounds, while 48 hours of germination reduced most of them. The main metabolic pathways causing these changes were identified as phenylalanine metabolism and the breakdown of aromatic compounds. Based on relative odor activity (rOAV), butanoic acid butyl ester, benzaldehyde, benzeneacetaldehyde, 2-octanol, 3-octanol, indole, and 2-acetyl-1-pyrroline were identified as the compounds contributing most to aroma formation. In conclusion, 24 hours of germination enhanced pleasant fruity, floral, and green aromas while reducing undesirable compounds such as indole, resulting in the optimal aroma profile; longer germination times negatively impacted aroma quality.

A recent study on the effect of germination on the aroma/aroma-active composition of legumes reported that a total of 61 volatile compounds were identified in peanut seeds germinated for 6 days using SPME-GC-MS, and 14 of these (6 aldehydes, 2 ketones, 4 alcohols, and 2 other compound groups) were determined as key odorants according to OAV values (Wang et al., 2026). Among these compounds, hexanal, benzeneacetaldehyde, and benzaldehyde were reported to increase during germination, while some alcohols, such as 1-hexanol, decreased. It was emphasized that these changes in the aldehyde and alcohol groups are related to the lipoxygenase-induced oxidation of unsaturated fatty acids, and that the formation of popcorn-flavored compounds such as 2-acetyl-1-pyrroline is related to proline-induced Maillard reactions. Furthermore, it has been reported that free amino acids such as glutamic acid, arginine, proline, and histidine play a precursor role in the synthesis of these OAV-based key aroma compounds. The study concluded that day 4 of germination constitutes a critical threshold for a balanced aroma-flavor profile where umami/sweet amino acids are optimized and bitter amino acids remain at moderate levels (Wang et al., 2026).

In the study conducted by Yang et al. (2025), the effect of 24-hour germination of soybeans on the aroma profile of soy milk was investigated. A total of 55 volatile compounds (5 alcohols, 15 aldehydes, 7 ketones, 4 esters, 12 acids, 8 alkanes, 2 nitrogenous compounds, 2 sulfurous compounds) were detected in the control, 0-hour and 24-hour germinated samples using HS-SPME-GC-MS; of these, 28 aroma-active compounds (4 alcohols, 8 aldehydes, 2 ketones, 3 esters, 3 furans, 2 alkanes, 3 acids, 2 nitrogenous compounds, 1 sulfurous compound) were identified whose odor activity was confirmed by olfactometric analysis. In the control group, the compounds with the highest FD were 1-octen-3-ol (mushroom-like), hexanal (grassy), and 3-methylthiopropanal (earthy), while in the 24-hour germinated sample, butyl acetate and ethyl acetate (fruity, floral, honey) compounds stood out, and the ester content increased. Sensory analysis also showed an increase in sweetness, paralleling the olfactometry results. It was reported that these changes were due to the conversion of unsaturated fatty acids to hexanal, 2-heptanone, and methyl isovalerate by the lipoxygenase enzyme activated by germination, and the increased protease activity supporting the conversion of amino acids to esters and alcohols (e.g., phenylalanine to benzaldehyde). In conclusion, 24 hours of germination was determined to be the optimum application point for reducing the undesirable soy odor and increasing sweet, nutty, and fruity notes in soybeans.

In a study where fava bean samples were germinated for 10 days and then dried and malted, it was reported that 22 aroma-active compounds (FD ≥ 8) were detected in raw fava bean samples and 26 in malted fava bean samples using the AEDA/GC-O method.

A general increase in aldehydes was observed with germination; while the intensity of hexanal (green, grassy) increased, heptanal (oily), methional (cooked potato), and benzaldehyde (bitter almond, marzipan), which were not present in the raw sample, became prominent in the malted samples. This situation was reported to be due to the increase in oxidation products of polyunsaturated fatty acids resulting from lipoxygenase enzyme activity in fava beans during germination. It has been reported that the most dominant and intense aroma-active compound in raw fava beans is 3-methylbutanoic acid (isovaleric acid, FD:512), which gives a cheesy/sour (sweaty) odor, and that the concentration of this compound decreases significantly (FD:4) after germination and drying. It has been considered that the decrease in 3-methylbutanoic acid may be related to the change in the metabolism dynamics of the leucine amino acid via the Ehrlich pathway through 3-methylbutanal. As a result of germination, β-damascenone (fruity, sweet, apple-like, honeyed), which is not present in raw fava beans and has a pleasant odor, emerged as the most dominant odor compound (FD:1024) in malt. It has been reported that the formation of this compound is attributed to the decomposition of carotenoid precursors such as neoxanthin by enzymatic pathways activated during germination and by a low level of thermal effect (drying was carried out at 50 °C). In conclusion, it has been reported that germination followed by drying improves the overall aroma profile of fava beans (Ritter et al., 2024).

CONCLUSION

Germination is a process that affects the aroma profile of cereals and legumes both positively and negatively. The studies examined indicate that in legumes rich in protein and lipids, germination predominantly triggers beany notes or fruity ester formation due to lipoxygenase activity and amino acid degradation; while in cereals and pseudocereals, phenylalanine metabolism, aromatic/heterocyclic compounds, and phenolic transformations are prominent depending on the germination time. While germination triggers the formation of pleasant fruity, floral, and nutty notes in many products, it can also lead to the emergence or increase of undesirable beany, earthy, and herbaceous compounds. The direction and intensity of these aroma changes vary depending on the type, variety, and especially the germination time; while short-term germination improves aroma quality, an excessive increase in undesirable compounds can be observed after a certain period. Therefore, it is recommended that future studies focus on optimizing germination conditions to be crop-specific and elucidating the underlying biochemical mechanisms at the molecular level in order to achieve the targeted aroma profile in food applications.

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CYP2C19 GENİNİN FARMAKOGENETİKDEKİ POTANSİYEL ROLÜNE BİYOİNFORMATİK BAKIŞ

A BIOINFORMATICS PERSPECTIVE ON THE POTENTIAL ROLE OF THE CYP2C19 GENE IN PHARMACOGENETICS

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ÖZET

Amaç

Sitokrom **(**CYP) enzimini kodlayan genler polimorfiktir ve çeşitli varyantlar ilacın aktivitesinde artış veya azalma ile ilişkilendirilmiştir. CYP450 enzimleri, 400-530 amino asitten yapılı proteinlerdir. Günümüzde, CYP enzimlerinin 57 aktif 58 yalancı genlerinin olduğu ve 434'den fazla alleli kodladığı bilinmektedir. İlaç metabolizması üzerindeki etkileriyle karakterize edilen 39 haplotip bulunmaktadır. CYP2C19 genetik heterojenliği, bireyler arasında önemli farmakokinetik farklılıklarla ilişkilidir ve bu da ilaç etkinliğini ve yan etki riskini etkiler. Çalışmamızda biyoinformatik araçlar kullanılarak CYP2C19'un hastalık patogenezindeki potansiyel rolünü değerlendirmek amaçlanmıştır.

Yöntemler

CYP2C19 geninin diğer genlerle ilişkisini belirlemek için Genemania/Gwas veritabanı kullanıldı, hedef miRNAları göstermek için miRDB veritabanı, diğer genlerle ilişkisini anlamak için String, MalaCards, GenCard veritabanları ve hastalıklardaki rolünü göstermek için Gwas veri tabanı kullanıldı. Yolak ve protein etkileşimleri için UniProt/KEGG veritabanı kullanıldı.

Sonuçlar

Genemania ve String veritabanları üzerinden yaptığımız incelemede CYP2C19 geninin; CYP2C9, CYP3A4, CYP3A5, CYP1A2, CYP4A11, CYP4F3, Epoksit hidrolaz 1) EPHX1, Peptidil-prolil cis-trans izomeraz G (PPIG) gibi genlerle yakın ilişkili olduğu bulunmuştur. CYP2C19'un en belirgin şekilde karaciğer dokusunda eksprese edildiği belirlendi (FDR skor: 0.00022). Hücresel düzeydeki spesifik yerleşiminin ise çoğunlukla düz yüzlü endoplazmik retikulumda olduğu bulundu (FDR skor: 3.06e-05). MiRDB veritabanı analizi sonucunda, CYP2C19 geninin 27 mikroRNA (miRNA) tarafından hedeflendiği saptanmıştır. Bunlardan skoru yüksek ilk üç tanesini hsa-miR-7157-5p (skor:92), hsa-miR-4310 (skor:90) ve hsa-miR-3617-3p (skor:85) olduğu görülmüştür. Gwas veritabanı ile yapılan analizde, antikoagülana yanıt, klopidogrel yanıtı, trombosit reaktivitesi etkinliği ile ilişkili bulunmuştur ($p=3 \times 10^{-7}$, 1×10^{-33}, 1×10^{-16}). MalaCards ve GeneCards veritabanı ile yapılan analizde CYP2C19 geninin, Tatton-Brown-Rahman overgrowth syndrome (FDR= 0,91) ilişkisi görülmüştür. MalaCards veritabanı ile yapılan analizde ise DNA Methyltransferase 3 Alpha (DNMT3A) (Skor:1701.94), Clathrin Heavy Chain (CLTC) (Skor: 10.6), Nuclear Receptor Binding SET Domain Protein 1 (NSD1) (Skor: 6.75) gibi genler ile de ilişkili olduğu tespit edildi. GeneCards Suite gen paylaşımına göre Tatton-Brown-Rahman Sendromu ile ilişkili olarak 10 hücresel bileşen bulundu. Bu bileşenlerden XY body (Skor:2.83), Catalytic complex (Skor: 2.66), Heterochromatin (Skor:2.36), Euchromatin (Skor: 2.26), Nuclear matrix (Skor: 1.95) skoru en yüksek hücresel bileşenler arasında tespit edildi. Uniport/KEGG veri tabanı, CYP2C19 geninin moleküler etkileşim reaksiyon ve ilişkili ağlarına baktığımızda; transport and catabolism, cell growth and death ve cellular comminity ve ayrıca metabolism pathways, Carbohydrate metabolism, Energy metabolism, Lipid metabolism gibi yolaklarda yer aldığını gösterdi.

Tartışma

Biyoinformatik araçlar kullanılarak yapılan bu çalışma CYP2C19 geninin özellikle metabolizmada önemli bir rol oynadığını gösteren bulgular sunmaktadır. Elde edilen bilgilerin CYP2C19'un işlevini ve ilaç metabolizmada yanıtlardaki rolünü ve kanser, nörodejeneratif hastalıklar, kardiyovasküler hastalıklarda bireysel tedavi yöntemlerinin geliştirilmesine katkıda bulunacağı düşünülmektedir.

Anahtar Kelimeler: CYP2C19, biyoinformatik, hastalık patogenezi, ilaç metabolizması

ABSTRACT

Objective

Genes encoding cytochrome (CYP) enzymes are polymorphic, and various variants have been associated with increased or decreased drug activity. CYP450 enzymes are proteins composed of 400-530 amino acids. Currently, it is known that there are 57 active and 58 pseudogenes of CYP enzymes, encoding more than 434 alleles. There are 39 haplotypes characterized by their effects on drug metabolism. CYP2C19 genetic heterogeneity is associated with significant pharmacokinetic differences between individuals, affecting drug efficacy and the risk of side effects. This study aimed to evaluate the potential role of CYP2C19 in disease pathogenesis using bioinformatics tools.

Methods

The Genemania/Gwas database was used to determine the relationship of the CYP2C19 gene with other genes, the miRDB database to identify target miRNAs, the String, MalaCards, and GenCard databases to understand its relationship with other genes, and the Gwas database to demonstrate its role in diseases. The UniProt/KEGG database was used for pathway and protein interactions.

Results

Our analysis of the Genemania and String databases revealed that the CYP2C19 gene is closely related to genes such as CYP2C9, CYP3A4, CYP3A5, CYP1A2, CYP4A11, CYP4F3, Epoxide hydrolase 1 (EPHX1), and Peptidyl-prolyl cis-trans isomerase G (PPIG). CYP2C19 was found to be most prominently expressed in liver tissue (FDR score: 0.00022). Its specific cellular localization was found to be primarily in the smooth endoplasmic reticulum (FDR score: 3.06e-05). Analysis of the miRDB database showed that the CYP2C19 gene is targeted by 27 microRNAs (miRNAs). The three genes with the highest scores were hsa-miR-7157-5p (score: 92), hsa-miR-4310 (score: 90), and hsa-miR-3617-3p (score: 85). Analysis using the GSAW database showed associations with anticoagulant response, clopidogrel response, and platelet reactivity ($p=3 \times 10^{-7}$, 1×10^{-33}, 1×10^{-16}). Analysis using the MalaCards and GeneCards databases revealed an association between the CYP2C19 gene and Tatton-Brown-Rahman overgrowth syndrome (FDR= 0.91). Analysis using the MalaCards database revealed associations with genes such as DNA Methyltransferase 3 Alpha (DNMT3A) (Score: 1701.94), Clathrin Heavy Chain (CLTC) (Score: 10.6), and Nuclear Receptor Binding SET Domain Protein 1 (NSD1) (Score: 6.75). According to the GeneCards Suite gene sharing, 10 cellular components were found to be associated with Tatton-Brown-Rahman Syndrome. Among these components, XY body (Score: 2.83), Catalytic complex (Score: 2.66), Heterochromatin (Score: 2.36), Euchromatin (Score: 2.26), and Nuclear matrix (Score: 1.95) were identified as having the highest scores. Looking at the molecular interaction reactions and related networks of the CYP2C19 gene in the Uniport/KEGG database; It has been shown to be involved in transport and catabolism, cell growth and death, and cellular community, as well as metabolism pathways such as carbohydrate metabolism, energy metabolism, and lipid metabolism.

Discussion

This study, using bioinformatics tools, presents findings demonstrating that the CYP2C19 gene plays a particularly important role in metabolism. It is believed that the information obtained will contribute to understanding the function of CYP2C19 and its role in drug metabolism responses, as well as to the development of personalized treatment methods for cancer, neurodegenerative diseases, and cardiovascular diseases.

Keywords: CYP2C19, bioinformatics, disease pathogenesis, drug metabolism.

GİRİŞ

Sitokrom P450 enzimleri faz I reaksiyonları içinde en önemli enzim grubudur. Sitokrom P450 monooksijenaz enzim sistemleri, matür eritrosit ve iskelet kası hücreleri dışında tüm memeli hücre tiplerinde ve prokaryotlarda bulunan hem-protein ailesidir. Bu sistem indüksiyon veya inhibisyon gibi sayısız mekanizmalarla değişime uğrayabilir ve bireyler arasında oldukça farklı formları ortaya çıkabilir. CYP450 enzimleri, 400-530 amino asitten yapılı proteinlerdir. Baz dizilimi benzerliklerine göre, P450 sistemi 55 farklı aile içinde sınıflandırılır.

CYP450 sisteminin tıpta çok önemli etkileri vardır: Bunlar; a) terapötik maddeleri inaktive veya aktive etme, b) kimyasal maddeleri oldukça yüksek derecede reaktif moleküllere dönüştürme ve istenmeyen hücre hasarı, hücre ölümü veya mutasyon gibi olaylara neden olma, c) steroid hormon sentezindeki bazı adımlara katılma ve d) yağ asidi ve bunların derivelerinin metabolizması gibi olaylardır P450 enzimlerinin hepatik ekspresyonunda belirgin farklılıklar vardır. CYPP450 enziminlerini kodlayan genler oldukça polimorfiktir ve bu enzimlerin çeşitli varyantları ilaçların aktivitesinde ve etkinliğinde artış veya azalma ile ilişkili olduğu belirtilmiştir. Genetik polimorfizm olarak adlandırılan bu olay toksisitenin neden bir hastada gözükürken diğerinde gözlenmediğini kısmen açıklamaktadır (Weinshilboum R,2003; Guengerich,2001;Ikemoto ve ark,1992).

Klinik uygulamalardaki bu enzimlerin etkinliklerini bireylerdeki genotip farklılığına göre ayırdığımızda, bireyler ilaç metabolizma hızlarına göre hızlı, çok hızlı, yavaş ve çok yavaş metabolize edenler olarak ayrılabilmektedir. İlaçların standart dozları hastaların büyük bir kısmında iyi sonuç vermektedir. Fakat bazı bireylerde standart dozlarla tedavi edilen bazı kişiler ilaçları daha hızlı metabolize ederler ve kullanılan bu dozlar bu kişilerde etkisiz kalmaktadır. Etkin bir tedavi için dozu arttırmak gerekebilir. İlacı yavaş metabolize eden enzime sahip bireylerde ise daha düşük dozda ilaca gereksinim olur çünkü standart dozlar ilacın toksik etkilere yol açmasına neden olmaktadır (Linder ve ark, 1997). Metabolizmadaki farklılıklar spesifik ilaç etkileşimlerine sebep olabildiği bildirilmiştir (Meyer, 1996). Her bir enzim için en yaygın ya da " wild-type-yabanıl tip" alel, "*1" olarak isimlendirilir ve mutant alleler ise *2, *3, *4 şeklinde isimlendirilir. Yabanıl tip alel genellikle normal enzim aktivitesini gösterir ama her zaman her olgu da böyle olmayabilir. Günümüzde, CYP enzimlerinin 57 aktif 58 yalancı genlerinin olduğu ve 434'den fazla aleli kodladığı bilinmektedir (Omari ve Murry, 2007).

Bu enzimlerden CYP2C geni 27 bp uzunluğundadır. Bu alt ailelerin tüm üyelerinin polimorfik yapıları ile ilaç metabolizması çeşitli popülasyonlarda araştırılmaktadır. CYP2C8, CYP2C9, CYP2C18, CYP2C19 formları bulunmaktadır. Bunlardan kromozom yerleşimi 10q24.1 olan CYP2C19 geni polimorfik olarak tanımlanmıştır. CYP2C19 enziminin geni 1473 baz çifti uzunluğunda dokuz ekzon içerir ve 490 amino asitten meydana gelen bir proteini kodlar. CYP2C19, 92.867 baz çifti DNA'yı kapsamaktadır (Shimada, ve Mernaugh ve, Guengerich, 2005). CYP2C19, klinikte sıklıkla reçelenmekte olan diazepam, mephenytoin, proton pompa inhibitörleri [(PPI) (lansoprazolon), omeprazole, pantoprazole)], fenitoin, barbitüratlar, antidepresanlar, klopidogrel gibi trombosit önleyici ilaçlar gibi birçok ilacın metabolizmasından sorumludur. Ayrıca karsinogenlerin detoksifikasyonu ya da inaktivasyonunda da rol oynamaktadır.

CYP2C19 geniyle ilgili olarak Bağlanma ve Katalitik aktiviteye ilişkin 2 farklı kategoride 14 moleküler fonksiyon bulunmuştur. Bu fonksiyonlar: bağlanma kategorisinde enzim bağlanmasını, Heme bağlanmasını, demir iyonu bağlanmasını, metal iyonu bağlanması, oksijen bağlanmasını sağlamaktadır. Katalitik aktivite olarak ise, (R)-limonen 6-monooksijenaz aktivitesini etkinleştirir, (S)-limonen 6-monooksijenaz aktivitesini etkinleştirir, (S)-limonen 7-monooksijenaz aktivitesini etkinleştirir, Uzun zincirli yağ asidi omega-1 hidroksilaz aktivitesini etkinleştirir, Monooksijenaz aktivitesini etkinleştirmesi olarak sayılabilmektedir (Shimada, ve Mernaugh ve, Guengerich, 2005; Goldstein ve ark, 1994). CYP2C19 geninin ürünü, öncelikle karaciğerde ifade edilen ve ksenobiyotik ve endojen lipid metabolizmasında rol oynayan bir sitokrom P450 monooksijenazdır. Hidroksilasyon ve epoksidasyon reaksiyonlarını katalize eder**,** özellikle S-mefenitoin ve omeprazol metabolize eder ve çoklu doymamış yağ asitlerini omega-1 pozisyonunda hidroksile ederek biyolojik olarak aktif lipid aracı maddelerinin üretimine katkıda bulunmaktadır. CYP2C19**,** ilaçlar ve çevresel bileşikler tarafından indüklenir ve zayıf metabolizör fenotipleriyle bağlantılı genetik polimorfizm sergileyerek terapötik ilaç yanıtını etkilemektadir. (https://www.genecards.org/card/CYP2C19#Function). CYP2C19'un normal aktiviteli aleli CYP2C19*1'dir. CYP2C19'un genetik polimorfizmine dayanarak, vahşi tip homozigot CYP2C19*1*1 güçlü bir metabolizördür. Bununla birlikte, CYP2C19 fonksiyon kaybı (LOF) alellerini (*2, *3, *4, *5) taşıyanlar daha zayıf metabolizörlerdir. CYP2C19'un genotipleri hızlı metabolizer (Rapid matabolizer-RM), orta metabolizer (Intermediate metabolizer-IM) ve zayıf metabolizer (Poor metabolizer-PM) olarak sınıflandırılmaktadır (Inoue, ve Yamazaki, ve Shimada,1998).

Ondan fazla aleli tanımlanmıştır. CYP2C19*2 ve *3 bilinen mutant alellerdir. CYP2C19*2, 5.ekzonda 681.baz çiftinde Guanin----Adenin değişmesi ile meydana gelmektedir. Bu mutasyon alellerini taşıyan kişiler enzim aktiviteleri olmadığı için zayıf metabolize edici bireyler olarak tanımlanırlar.

Yavaş metabolize edici bireylerde ilaçların konsantrasyon-zaman eğrisi altında kalan alanların (AUC) daha yüksek değerlere ulaştığı gösterilmiştir (Inoue, ve Yamazaki, ve Shimada,1998). CYP2C19 geninin ilaç metabolizması üzerindeki etkileriyle karakterize edilen 39 haplotip bulunmaktadır. Bu CYP2C19 genetik heterojenliği, bireyler arasında önemli farmakokinetik farklılıklarla ilişkilidir ve bu da ilaç etkinliğini ve yan etki riskini etkilemektedir. Enzim farmakokinetiğinde CYP2C19, esas olarak karaciğerde ifade edilen, indüklenebilir bir faz-bir enzimdir. Özellikle çoklu ilaç kullanımının yaygın olduğu yaşlılarda, ilaç-ilaç etkileşimleri (CYP2C19 inhibitörleri ve indükleyicileriyle) büyük önem taşımaktadır (Scott ve ark,2012; Botton ve ark, 2021).

Diğer CYP genlerinde olduğu gibi, CYP2C19'daki genetik varyasyon ve değişken hepatik ekspresyonu, CYP2C19 enziminin substratlarının metabolizmasında bireyler arası değişkenliğe katkıda bulunduğu bildirilmiştir. Bir ilacın (veya metabolitlerinin) plazma konsantrasyonu, enzim aktivitesindeki genetik olarak belirlenmiş heterojenlik nedeniyle hastalar arasında önemli ölçüde değişebilir olduğu belirtilmiştir. Fonksiyonel olarak önemli varyantlar için genomik testlerle tahmin edilebilirliği üzerinde bilgiler mevcuttur. İlgili varyantlar arasında amino asit değiştiren tek nükleotid varyantları, ekleme varyantları ve delesyonlar bulunur (Botton ve ark, 2021).

Bireyler, CYP2C19 substratlarını metabolize etme yeteneklerine bağlı olarak sınıflandırılabilir ve sınıflandırma, bireyin genotipindeki (diplotip olarak da adlandırılır) en yüksek işlevli CYP2C19 aleline dayanır. Aleller, işlevsiz, azalmış işlevli, normal işlevli, belirsiz işlevli veya artmış işlevli olarak tanımlanır ve bir genotipte bulunan alel kombinasyonu, bireyin metabolizör fenotipinin tahmin edilmesini sağlar. Bir bireyin tahmini fenotipi, genotipinin (diplotip) iki aleline dayanmaktadır. CYP2C19 Metabolizör Durumunun Yorumlanmasında ise; fonksiyonel sınıflandırma için, bir bireyin CYP2C19 metabolizör fenotipini beş kategori olmak üzere: zayıf, orta, normal, hızlı, ve ultra hızlı olarak tanımlanmıştır. Zayıf Metabolizör (PM): Düşük/hiç enzim aktivitesi olmaması, daha yüksek ilaç seviyelerine yol açar. Orta Düzey Metabolizör (IM): Azalmış enzim aktivitesi. Geniş (Normal) Metabolizör (EM/NM): Normal enzim aktivitesi. Ultra Hızlı Metabolizör (UM): Yüksek enzim aktivitesi, daha düşük ilaç seviyelerine yol açmaktadır (Scott ve ark,2012; Ingelman-Sundberg, ve Sim, ve Gomez, ve Rodriguez-Antona, 2007). Klinik olarak önemi ise özellikle klopidogrel gibi ilaçlarda reçete etmeden önce, dozaj veya ilaç seçimini yönlendirmek için hastanın genotipini belirlemek için kullanılır (Scott ve ark,2012).

Popülasyonlar arasında ve içinde CYP2C19 alel sıklığında küresel farklılıklar vardır. Örneğin, İngiltere'deki beyaz bireylerin yaklaşık %20-30'unda CYP2C19'da en az bir işlev kaybı varyantı bulunurken, bu oran Doğu Asya popülasyonlarında yaklaşık %50-60'a yükselir. Popülasyonlar içindeki belirli alellerin sıklığı, farmakogenomik testin faydasını gösterebilir; ancak klinik öneriler, bireyin metabolizör fenotipine dayanmaktadır. Sıklık: CYP2C19*2 ve *3.ve varyantları, Afrika (yaklaşık %17) veya Caucasion (yaklaşık %15) popülasyonlarına kıyasla Asya popülasyonlarında (yaklaşık %35) daha yaygındır (Botton ve ark, 2021).

Proton pompa inhibitörleri (PPI) genellikle gastroözofageal reflü hastalığı, mide ve duodenum ülseri hastalığı, Helicobacter pylori (H. pylori) enfeksiyonunun eradikasyonu, nonsteroidal antiinflamatuar ilaçlarla ilişkili hasarın önlenmesi, tedavisi ve ayrıca varis dışı üst gastrointestinal kanama veya ülser dışı dispepsi olan hastalar için reçete edilen ilaçlardandır. Çoğu PPI'ın ağırlıklı olarak CYP2C19 tarafından metabolize edildiği bildirilmiştir. Hem orta metabolize hem de zayıf metabolizerler, normal metabolizerler bireylere kıyasla daha düşük ilaç eliminasyonuna ve daha yüksek PPI plazma konsantrasyonlarına sahip olabildiği rapor edilmiştir (Furuta ve ark, 1998). Her ne kadar CYP2C19 varyantını sorgulamak için bir dizi genotipleme teknolojisi kullanılabilirse de Klinik Laboratuvar İyileştirme Değişiklikleri onaylı laboratuvarlardaki aleller, iki genotipleme platformları ABD Gıda ve İlaç İdaresi tarafından onaylanmış olduğu bildirilmiştir. AmpliChip CYP450 Testi (Roche Molecular Systems, Inc., Pleasanton, Kaliforniya, ABD) CYP2C19*2 ve *3'ü (artı CYP2D6 varyantını) sorgulayan aleller) ve Infiniti CYP2C19 Testi (AutoGenomics, Inc., Vista, California, ABD) CYP2C19*2, *3 ve *17'yi sorgulamaktadır (Scott ve ark, 2011).

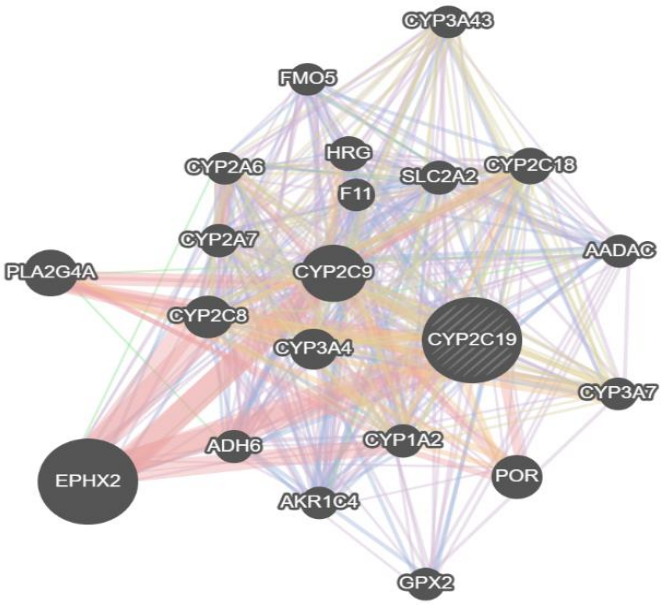
CYP2C19 genetik heterojenliği, bireyler arasında önemli farmakokinetik farklılıklarla ilişkilidir ve bu da ilaç etkinliğini ve yan etki riskini etkiler. Bu çalışmamızda biyoinformatik araçlar kullanılarak CYP2C19'un hastalık patogenezindeki potansiyel rolünü değerlendirmek amaçlanmıştır.

YÖNTEM

CYP2C19 geninin diğer genlerle ilişkisini belirlemek için Genemania/Gwas veritabanı kullanıldı, hedef miRNAları göstermek için miRDB veritabanı, diğer genlerle ilişkisini anlamak için String, MalaCards, GenCard veritabanları ve hastalıklardaki rolünü göstermek için Gwas veri tabanı kullanıldı. Yolak ve protein etkileşimleri için UniProt/KEGG veritabanı kullanıldı.

BULGULAR

CYC2C19 geninin diğer genler ile bağlantısına baktığımızda; Genemania ve String veritabanları üzerinden yaptığımız incelemede CYP2C19 geninin; CYP2C9, CYP3A4, CYP3A5, CYP1A2, CYP4A11, CYP4F3, Epoksit hidrolaz 1) EPHX1, Peptidil-prolil cis-trans izomeraz G (PPIG) gibi genlerle yakın ilişkili olduğu bulunmuştur (Şekil 1).



Şekil 1. https://genemania.org/search/homo-sapiens/CYP2C19

CYP2C19'un en belirgin şekilde karaciğer dokusunda eksprese edildiği belirlendi (FDR skor: 0.00022). Hücresel düzeydeki spesifik yerleşiminin ise çoğunlukla düz yüzlü endoplazmik retikulumda olduğu bulundu (FDR skor: 3.06e-05) (Şekil 2).

Anatomical entity	Expression score	FDR
UBERON:0002107 liver	93.26	<= 1.00e-14
UBERON:0002114 duodenum	92.82	<= 1.00e-14
UBERON:0001114 right lobe of liver	92.50	<= 1.00e-14
UBERON:0035834 lower esophagus mucosa	76.94	3.83e-8
UBERON:0003454 small intestine Peyer's patch	70.88	2.08e-13
UBERON:0002110 gall bladder	65.11	1.26e-9
UBERON:0001199 mucosa of stomach	63.41	9.38e-6
UBERON:0001161 body of stomach	59.61	5.58e-11
UBERON:0004991 mucosa of transverse colon	58.74	7.43e-5
UBERON:0000996 vagina	50.77	3.10e-6
UBERON:0001160 fundus of stomach	47.81	1.29e-5
UBERON:0001416 skin of abdomen	47.78	5.36e-4

Şekil 2. https://www.genecards.org/card/CYP2C19#Expression

MiRDB veritabanı analizi sonucunda, CYP2C19 geninin 27 mikroRNA (miRNA) tarafından hedeflendiği saptanmıştır. Bunlardan skoru yüksek ilk üç tanesini hsa-miR-7157-5p (skor:92), hsa-miR-4310 (skor:90) ve hsa-miR-3617-3p (skor:85) olduğu görülmüştür (Şekil 3).

Gene 1557 is predicted to be targeted by 27 miRNAs in miRDB.

Target Detail	Target Rank	Target Score	miRNA Name	Gene Symbol	Gene Description
Details	1	92	hsa-miR-7157-5p	CYP2C19	cytochrome P450 family 2 subfamily C member 19
Details	2	90	hsa-miR-4310	CYP2C19	cytochrome P450 family 2 subfamily C member 19
Details	3	85	hsa-miR-3617-3p	CYP2C19	cytochrome P450 family 2 subfamily C member 19
Details	4	81	hsa-miR-1275	CYP2C19	cytochrome P450 family 2 subfamily C member 19
Details	5	78	hsa-miR-5584-5p	CYP2C19	cytochrome P450 family 2 subfamily C member 19
Details	6	75	hsa-miR-891a-3p	CYP2C19	cytochrome P450 family 2 subfamily C member 19
Details	7	74	hsa-miR-4665-5p	CYP2C19	cytochrome P450 family 2 subfamily C member 19
Details	8	74	hsa-miR-7112-3p	CYP2C19	cytochrome P450 family 2 subfamily C member 19
Details	9	71	hsa-miR-369-3p	CYP2C19	cytochrome P450 family 2 subfamily C member 19
Details	10	69	hsa-miR-507	CYP2C19	cytochrome P450 family 2 subfamily C member 19
Details	11	69	hsa-miR-557	CYP2C19	cytochrome P450 family 2 subfamily C member 19
Details	12	68	hsa-miR-4776-5p	CYP2C19	cytochrome P450 family 2 subfamily C member 19
Details	13	66	hsa-miR-138-2-3p	CYP2C19	cytochrome P450 family 2 subfamily C member 19
Details	14	66	hsa-miR-7515	CYP2C19	cytochrome P450 family 2 subfamily C member 19
Details	15	62	hsa-miR-4443	CYP2C19	cytochrome P450 family 2 subfamily C member 19
Details	16	61	hsa-miR-6890-5p	CYP2C19	cytochrome P450 family 2 subfamily C member 19
Details	17	57	hsa-miR-4478	CYP2C19	cytochrome P450 family 2 subfamily C member 19
Details	18	56	hsa-miR-4668-5p	CYP2C19	cytochrome P450 family 2 subfamily C member 19
Details	19	55	hsa-miR-4725-3p	CYP2C19	cytochrome P450 family 2 subfamily C member 19
Details	20	55	hsa-miR-2110	CYP2C19	cytochrome P450 family 2 subfamily C member 19
Details	21	55	hsa-miR-6780b-5p	CYP2C19	cytochrome P450 family 2 subfamily C member 19
Details	22	52	hsa-miR-4802-5p	CYP2C19	cytochrome P450 family 2 subfamily C member 19
Details	23	52	hsa-miR-4520-2-3p	CYP2C19	cytochrome P450 family 2 subfamily C member 19
Details	24	52	hsa-miR-1843	CYP2C19	cytochrome P450 family 2 subfamily C member 19
Details	25	52	hsa-miR-3675-5p	CYP2C19	cytochrome P450 family 2 subfamily C member 19
Details	26	51	hsa-miR-379-3p	CYP2C19	cytochrome P450 family 2 subfamily C member 19
Details	27	51	hsa-miR-411-3p	CYP2C19	cytochrome P450 family 2 subfamily C member 19

Şekil 3. https://mirdb.org/cgi-bin/search.cgi

CYP2C19 geni için**,** Nörolojik ajanlar, Kardiyovasküler ve hematolojik ajanlar, Metabolizma, Antikanser ajanlar, Klasik metabolik yol, Ağrı, antiinflamatuar ve immünomodülatör ajanlar, Sinyalizasyon yolu, Gastrointestinal ajanlar, Düzenleyici yol, Endokrin ve Metabolik Hastalık ajanları, Solunum yolu ajanları, Anti-enfektif ajanlar, Fizyolojik mekanizmalar, Hastalık yolu ve İlaç ADME kategorileri de dahil olmak üzere 85 yolak ilişkili bulunmaktadır (https://www.genecards.org/card/CYP2C19#Pathways).

Gwas veritabanı ile yapılan analizde, antikoagülana yanıt, klopidogrel yanıtı, trombosit reaktivitesi etkinliği ile ilişkili bulunmuştur ($p=3 \times 10^{-7}$, 1×10^{-33}, 1×10^{-16}). MalaCards ve GeneCards veritabanı ile yapılan analizde CYP2C19 geninin, Tatton-Brown-Rahman overgrowth syndrome (FDR= 0,91) ilişkisi görülmüştür (https://www.genecards.org/card/CYP2C19#Function).

MalaCards veritabanı ile yapılan analizde ise DNA Methyltransferase 3 Alpha (DNMT3A) (Skor:1701.94), Clathrin Heavy Chain (CLTC) (Skor: 10.6), Nuclear Receptor Binding SET Domain Protein 1 (NSD1) (Skor: 6.75) gibi genler ile de ilişkili olduğu tespit edildi (https://www.malacards.org/search/results?q=CYP2C19). GeneCards Suite gen paylaşımına göre Tatton-Brown-Rahman Sendromu ile ilişkili olarak 10 hücresel bileşen bulundu. Bu bileşenlerden XY body (Skor:2.83), Catalytic complex (Skor: 2.66), Heterochromatin (Skor:2.36), Euchromatin (Skor: 2.26), Nuclear matrix (Skor: 1.95) skoru en yüksek hücresel bileşenler arasında tespit edildi (https://www.genecards.org/card/CYP2C19#Pathways). Uniport/KEGG veri tabanı, CYP2C19 geninin moleküler etkileşim reaksiyon ve ilişkili ağlarına baktığımızda; transport and catabolism, cell growth and death ve cellular comminity ve ayrıca metabolism pathways, Carbohydrate metabolism, Energy metabolism, Lipid metabolism gibi yolaklarda yer aldığını gösterdi (https://www.kegg.jp/keggbin/search_pathway_text?map=map&keyword=CYP2C19&mode=1&viewImage=true).

SONUÇ

Biyoinformatik araçlar kullanılarak yapılan bu çalışma CYP2C19 geninin özellikle metabolizmada önemli bir rol oynadığını gösteren bulgular sunmaktadır. Elde edilen bilgilerin CYP2C19'un işlevini ve ilaç metabolizmada yanıtlardaki rolünü ve kanser, nörodejeneratif hastalıklar, kardiyovasküler hastalıklarda bireysel tedavi yöntemlerinin geliştirilmesine katkıda bulunacağı düşünülmektedir.

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ŞERBETÇİ OTU (HUMULUS LUPULUS L.) ÖZÜTÜNÜN FARKLI KONSANTRASYONLARININ YEM BEZELYESİNDE (PISUM SATIVUM L.) ÇİMLENME VE ERKEN FİDE GELİŞİMİ ÜZERİNE ETKİSİ

EFFECTS OF DIFFERENT CONCENTRATIONS OF HOP (HUMULUS LUPULUS L.) EXTRACT ON SEED GERMINATION AND EARLY SEEDLING GROWTH OF FORAGE PEA (PISUM SATIVUM L.)

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ÖZET
Allelopati, bitkiler tarafından üretilen biyolojik aktif bileşiklerin başka bitkilerin çimlenme ve gelişim süreçlerini olumlu veya olumsuz yönde etkilemesi olarak tanımlanmaktadır. Bu çalışma, farklı konsantrasyonlarda uygulanan şerbetçi otu (*Humulus lupulus* L.) özütünün yem bezelyesinin *(Pisum sativum* L.) çimlenmesi ve erken fide gelişimi üzerindeki etkilerini belirlemek amacıyla yürütülmüştür. Araştırmada kontrol (%0) ile birlikte %25, %50, %75 ve %100 şerbetçi otu özütü dozları değerlendirilmiştir. Çalışmada çimlenme oranı (ÇO), kök uzunluğu (KU), gövde uzunluğu (GU), kök yaş ağırlığı (KYA), gövde yaş ağırlığı (GYA), kök kuru ağırlığı (KKA) ve gövde kuru ağırlığı (GKA) incelenmiştir. Araştırma sonucunda, özüt dozlarının ÇO, KU ve GU üzerine etkisi istatistiksel olarak önemsiz bulunurken, KYA, GYA, KKA ve GKA üzerindeki etkisi önemli bulunmuştur ($p<0.01$). Çimlenme oranı %94.00–100.00, kök uzunluğu 4.96–5.76 cm ve gövde uzunluğu 8.84–10.79 cm arasında değişmiştir. Kök yaş ağırlığı 0.595–0.763 g, gövde yaş ağırlığı 1.528–2.526 g, kök kuru ağırlığı 0.152–0.225 g ve gövde kuru ağırlığı 0.280–0.444 g arasında değişmiştir. Kök ve gövde yaş ve kuru ağırlıklarının tamamında en yüksek değerler %75 şerbetçi otu özütü uygulamasında belirlenmiştir. Buna karşılık, %100 dozunda söz konusu özelliklerde yeniden azalma meydana gelmiştir. Sonuç olarak, şerbetçi otu özütünün yem bezelyesinin çimlenme oranı ve fide boy gelişimi üzerinde belirgin bir etkisi bulunmazken, erken dönem biyokütle gelişimini önemli ölçüde etkilediği belirlenmiştir. Özellikle %75 dozunun yem bezelyesinde erken fide biyokütlesinin artırılması bakımından öne çıktığı ve şerbetçi otunun allelopatik potansiyelinin dozlara bağlı olarak değişebildiği sonucuna varılmıştır.
Anahtar Kelimeler: Yem bezelyesi, şerbetçi otu özütü, allelopati, çimlenme, fide gelişimi.

ABSTRACT
Allelopathy refers to the stimulatory or inhibitory influence that biologically active compounds released by one plant exert on the germination and growth of other plants. This study investigated the effects of varying concentrations of hop (*Humulus lupulus* L.) extract on seed germination and early seedling development of forage pea (*Pisum sativum* L.). Five extract concentrations were tested: a distilled-water control (0%) and 25%, 50%, 75%, and 100%. The measured parameters were germination percentage (GP), root length (RL), shoot length (SL), root fresh weight (RFW), shoot fresh weight (SFW), root dry weight (RDW), and shoot dry weight (SDW). Extract concentration had no statistically significant effect on GP, RL, or SL, but significantly affected all biomass parameters (RFW, SFW, RDW, SDW; $p<0.01$). GP ranged from 94.00 to 100.00%, RL from 4.96 to 5.76 cm, and SL from 8.84 to 10.79 cm. RFW, SFW, RDW, and SDW ranged from 0.595–0.763 g, 1.528–2.526 g, 0.152–0.225 g, and 0.280–0.444 g, respectively. All biomass parameters peaked at 75% extract concentration and declined at 100%, indicating a non-linear, concentration-dependent response. These findings suggest that hop extract does not impair seed germination or seedling elongation of forage pea, but markedly promotes early biomass accumulation at sub-maximal concentrations. The 75% treatment emerged as the most effective concentration for enhancing early seedling biomass, highlighting the dose-dependent nature of H. lupulus allelopathic activity.
Keywords: Forage pea, hop extract, allelopathy, germination, seedling growth.

1. GİRİŞ

Allelopati, bir bitkinin çevresine saldığı biyolojik olarak aktif bileşikler aracılığıyla başka bitkilerin çimlenme ve gelişme süreçlerini olumlu veya olumsuz yönde etkilemesi olarak tanımlanmaktadır. Bitkilerden elde edilen farklı özütlerin tohum çimlenmesi, kök gelişimi ve fide büyümesi üzerinde önemli etkiler oluşturabildiği ve bu etkinin kullanılan bitki türüne ve özüt konsantrasyonuna göre değişebildiği bildirilmektedir (Kadıoğlu ve Yanar, 2004). Bu nedenle bitki özütlerinin allelopatik özelliklerinin belirlenmesi, türler arasındaki biyokimyasal etkileşimlerin ortaya konulması ve doğal kaynaklı biyolojik aktivite gösteren materyallerin değerlendirilmesi açısından önem taşımaktadır. Nitekim farklı bitki özütleriyle yürütülen çalışmalarda, bazı türlerin tohum çimlenmesini teşvik ederken bazılarının ise çimlenme ve erken fide gelişimini baskılayabildiği ortaya konulmuştur.

Şerbetçi otu (*Humulus lupulus* L.), özellikle kozalaklarında bulunan reçineler, fenolik bileşikler, flavonoidler ve diğer sekonder metabolitler bakımından zengin bir bitkidir. Bu bileşiklerin farklı biyolojik aktivitelere sahip olduğu ve H. lupulus özütlerinin biyolojik olarak aktif özellikler gösterdiği bildirilmiştir (Korpelainen & Pietiläinen, 2021; Yılar et al., 2020). Nitekim farklı bitki ekstraktlarının biyolojik aktivitelerinin değerlendirildiği çalışmalarda, bitki özütlerinin mikroorganizmalar ve diğer biyolojik sistemler üzerinde önemli etkiler oluşturabildiği bildirilmiştir (Atmaca et al., 2021). Şerbetçi otu özütünün allelopatik potansiyelini doğrudan değerlendiren bir çalışmada, H. lupulus özütünün mısır (*Zea mays* L.) ve fasulye (*Phaseolus vulgaris* L.) tohumlarının çimlenmesi ve fide gelişimi üzerinde etkili olduğu; farklı özüt konsantrasyonlarının her iki türün çimlenme ve fide gelişim dinamiklerini değiştirdiği bildirilmiştir (Marian et al., 2017). Ayrıca, şerbetçi otu rizosferinden elde edilen ekstraktlarda biyolojik aktif bileşiklerin belirlenmiş olması ve bu bileşiklerin biyolojik aktivite göstermesi, H. lupulus'un bitkiler arası kimyasal etkileşimler bakımından da dikkate değer bir tür olduğunu göstermektedir (Zhang et al., 2011).

Yem bezelyesi (*Pisum sativum* L.), yüksek protein içeriği ve kaba yem üretimindeki kullanım alanı nedeniyle önemli bir baklagil yem bitkisidir. Baklagil türlerinin çimlenme ve erken fide gelişimleri, çevrede bulunan veya diğer bitkiler tarafından salgılanan biyolojik aktif bileşiklerden etkilenebilmektedir (Kadıoğlu and Yanar, 2004; Marian et al., 2017). Bitki özütlerinin çimlenme ve fide gelişimi üzerindeki etkisinin; kullanılan bitki türüne, özüt konsantrasyonuna ve test bitkisinin duyarlılığına bağlı olarak değişebildiği bildirilmektedir (Acar et al., 2019; Leblebici et al., 2024). Özellikle kök ve gövde gelişiminin birlikte değerlendirilmesi, allelopatik etkinin yalnızca çimlenme üzerindeki etkisinin değil, fide gelişiminin erken dönemlerindeki sonuçlarının da ortaya konulmasına olanak sağlamaktadır (Acar et al., 2019). Bu bağlamda, şerbetçi otu özütünün yem bezelyesinin çimlenme ve erken fide gelişimi üzerindeki etkilerinin belirlenmesi, H. lupulus'un potansiyel allelopatik özelliklerinin ortaya konulması açısından önem taşımaktadır. Bu çalışmada, farklı konsantrasyonlarda hazırlanan şerbetçi otu özütünün yem bezelyesinin çimlenme oranı, kök ve gövde boyu ile kök ve gövde yaş ve kuru ağırlıkları üzerindeki etkilerinin belirlenmesi amaçlanmıştır.

2. MATERYAL VE YÖNTEM

Allelopatik çalışmada kullanılan şerbetçi otu (*Humulus lupulus* L.) materyali, Bilecik ilinde bir çiftçi arazisinden temin edilmiştir. Bitki materyali hasat edildikten sonra laboratuvara getirilmiş ve ekstrakt hazırlanması amacıyla kullanılmıştır. Şerbetçi otu materyalinden 500 g tartılarak 3 L saf su içerisinde bekletilmiş ve 7 saatlik ekstraksiyon süresinin ardından elde edilen süzüntü farklı konsantrasyonlarda seyreltilerek uygulama çözeltileri hazırlanmıştır. Uygulamalarda %100, %75, %50, %25 ve %0 olmak üzere beş farklı ekstrakt konsantrasyonu kullanılmıştır. %0 uygulaması yalnızca saf su içeren kontrol grubu olarak değerlendirilmiştir.

Çalışmada allelopatik etkinin belirlenmesinde test bitkisi olarak yem bezelyesi (*Pisum sativum* L. "Kirazlı") tohumları kullanılmıştır. Deneme, Bilecik Şeyh Edebali Üniversitesi Tarımsal Araştırma ve Uygulama alanında bulunan laboratuvarda, Tesadüf Parselleri Deneme Desenine göre dört tekerrürlü olarak yürütülmüştür. Her petri kabına 20 adet yem bezelyesi tohumu yerleştirilmiş ve hazırlanan şerbetçi otu ekstraktları ile gün aşırı olacak şekilde 10 mL uygulanmıştır. Çimlenmenin başlangıcı, radikulanın gelişerek kurutma kâğıdına temas ettiği dönem olarak kabul edilmiştir. Deneme süresince ortam sıcaklığı 23–25 °C, bağıl nem yaklaşık %60 ve fotoperiyot 16 saat aydınlık/8 saat karanlık olacak şekilde düzenlenmiş ve uygulamalar 21 gün boyunca sürdürülmüştür (Karakurt ve ark., 2010).

Çimlenmenin başlamasından itibaren her gün çimlenen tohumlar sayılarak kaydedilmiş ve farklı şerbetçi otu ekstrakt konsantrasyonlarının yem bezelyesinin çimlenmesi üzerindeki etkileri değerlendirilmişti
Deneme süresince şerbetçi otu ekstraktlarının yem bezelyesinin çimlenmesi ve fide gelişimi üzerindeki etkilerini belirlemek amacıyla çimlenme oranı, kök boyu, gövde boyu, kök yaş ağırlığı, gövde yaş ağırlığı, kök kuru ağırlığı ve gövde kuru ağırlığı incelenmiştir. Çimlenme oranı, çimlenen tohum sayısının toplam tohum sayısına oranlanmasıyla aşağıdaki eşitlik kullanılarak hesaplanmıştır (Kayacetin ve ark., 2018):
Çimlenme oranı (%) = (Çimlenen tohum sayısı / Toplam tohum sayısı) × 100
Çimlenme süresi sonunda fidelerin kök ve gövde kısımları birbirinden ayrılarak kök boyu ve gövde boyu cetvel yardımıyla cm olarak ölçülmüştür. Toplam fide boyu, kök ve gövde boylarının toplamı alınarak belirlenmiştir. Kök ve gövde yaş ağırlıklarının belirlenmesinde, fidelerin kök ve gövde kısımları ayrıldıktan sonra doğrudan tartımları yapılmıştır. Daha sonra örnekler sabit ağırlığa ulaşıncaya kadar kurutulmuş ve tartılarak kök ve gövde kuru ağırlıkları belirlenmiştir.
Deneme sonunda elde edilen veriler, Tesadüf Parselleri Deneme Desenine uygun olarak SPSS 21.0 paket programında varyans analizine tabi tutulmuştur. Şerbetçi otu ekstrakt konsantrasyonları arasındaki farklılıkların belirlenmesinde Duncan çoklu karşılaştırma testi kullanılmış ve istatistiksel önem düzeyi $p<0.05$ olarak kabul edilmiştir.

3. BULGULAR VE TARTIŞMA

Tablo 1'de, farklı şerbetçi otu (Humulus lupulus L.) özütü dozlarının yem bezelyesinin çimlenme ve fide gelişimi özellikleri üzerine etkileri verilmiştir. İncelenen özellikler; çimlenme oranı (ÇO), kök uzunluğu (KU), gövde uzunluğu (GU), kök yaş ağırlığı (KYA), gövde yaş ağırlığı (GYA), kök kuru ağırlığı (KKA) ve gövde kuru ağırlığı (GKA) olarak belirlenmiştir.
Şerbetçi otu özütü dozlarının yem bezelyesinin ÇO, KU ve GU özellikleri üzerine etkisi istatistiksel olarak önemsiz bulunmuştur. ÇO %94.00–100.00, KU 4.96–5.76 cm ve GU 8.84–10.79 cm arasında değişmiştir. ÇO bakımından en yüksek değer %25 dozunda (%100.00), en düşük değer ise %50 dozunda (%94.00) belirlenmiştir. KU ve GU bakımından en yüksek değerler yine %25 dozunda sırasıyla 5.76 ve 10.79 cm olarak elde edilmiştir. Ancak bu farklılıkların istatistiksel olarak önemli olmaması, uygulanan şerbetçi otu özütü dozlarının yem bezelyesinin çimlenme ve fide boy gelişimi üzerinde belirgin bir etki oluşturmadığını göstermektedir. Benzer şekilde, Acar ve ark. (2019), farklı gelişme dönemlerinden elde edilen *Bituminaria bituminosa* yaprak ekstraktlarının buğdayın çimlenme ve fide gelişimi üzerinde farklı etkiler oluşturduğunu, etkinin ekstraktın kaynağı ve uygulama düzeyine göre değişebildiğini bildirmiştir.
Buna karşılık, şerbetçi otu özütü dozlarının KYA, GYA, KKA ve GKA üzerine etkisi istatistiksel olarak önemli bulunmuştur ($p<0.01$). KYA 0.595–0.763 g arasında değişmiş ve en yüksek değer %75 dozunda (0.763 g), en düşük değer ise %0 dozunda (0.595 g) belirlenmiştir. GYA bakımından değerler 1.528–2.526 g arasında değişmiş, en yüksek değer %75 dozunda (2.526 g), en düşük değer ise %0 dozunda (1.528 g) elde edilmiştir. KKA 0.152–0.225 g arasında değişmiş ve en yüksek değer %75 dozunda (0.225 g), en düşük değer ise %25 dozunda (0.152 g) bulunmuştur. GKA ise 0.280–0.444 g arasında değişmiş ve en yüksek değer %75 dozunda (0.444 g), en düşük değer %0 dozunda (0.280 g) belirlenmiştir. Özellikle %75 dozunda kök ve gövde yaş ve kuru ağırlıklarının tamamında en yüksek değerlerin elde edilmesi, bu dozun yem bezelyesinin erken dönem biyokütle gelişimi açısından öne çıktığını göstermektedir. Acar ve ark. (2019) da bitki ekstraktlarının buğdayda kök ve gövde yaş ve kuru ağırlıkları üzerinde farklı düzeylerde etkili olduğunu bildirmiştir.
Mevcut sonuçlar, Leblebici ve ark. (2024) tarafından yem şalgamı özütü kullanılarak mürdümük üzerinde yürütülen allelopati çalışmasıyla da benzerlik göstermektedir. Araştırıcılar, bitki özütlerinin etkisinin uygulama konsantrasyonuna bağlı olarak değişebildiğini ve belirli konsantrasyonlarda fide gelişiminin teşvik edilebildiğini, daha yüksek konsantrasyonlarda ise etkinin farklılaşabildiğini bildirmiştir. Mevcut çalışmada da %75 şerbetçi otu özütü dozunda KYA, GYA, KKA ve GKA değerlerinin en yüksek seviyeye ulaşması, ancak %100 dozunda bu değerlerin yeniden azalması, şerbetçi otu özütünün etkisinin doğrusal olmadığını ve konsantrasyona bağlı bir biyolojik yanıt oluşturduğunu düşündürmektedir. Benzer doz–yanıt davranışlarının farklı bitki özütleriyle yürütülen allelopati çalışmalarında da ortaya konulduğu bildirilmektedir (Acar ve ark., 2019; Leblebici ve ark., 2024).

Şerbetçi otu özütünün biyokütle parametreleri üzerindeki bu doza bağlı etkisinin, özütte bulunan biyolojik aktif bileşiklerle ilişkilendirilmesi mümkündür. H. lupulus kozalaklarında yüksek oranda bulunan alfa-asitler (humulon, kohumulon), beta-asitler (lupulon) ve ksantohumol gibi prenillenmiş flavonoidlerin, bitkisel hücre büyümesi ve bölünmesi üzerinde çift yönlü etkiler gösterebildiği bilinmektedir (Korpelainen & Pietiläinen, 2021). Düşük ve orta konsantrasyonlarda bu bileşikler, hücre zarı geçirgenliğini ve iyon alımını hafif ölçüde uyararak biyokütle birikimine katkıda bulunabilmektedir. Buna karşın yüksek konsantrasyonlarda, özellikle humulon türevlerinin antioksidan sistemleri üzerindeki baskılayıcı etkileri ve fenolik bileşiklerin toprak kökenli allelopatik çalışmalarında gözlemlendiğine benzer oksidatif stres mekanizmaları devreye girebilmektedir (Zhang et al., 2011). Bu çerçevede mevcut çalışmada gözlemlenen %75 dozundaki biyokütle teşviki ve %100 dozundaki gerilemenin, söz konusu biyoaktif bileşiklerin konsantrasyona bağlı uyarıcı-baskılayıcı denge eşiğini yansıttığı düşünülmektedir. Bununla birlikte, özütün tam bileşen profilinin ve her bir bileşenin yem bezelyesi fizyolojisi üzerindeki bireysel etkisinin ortaya konulabilmesi için ileri biyokimyasal analizlere ihtiyaç duyulmaktadır.

Tablo 1. Şerbetçi otu özütünün yem bezelyesinin çimlenme ve fide gelişim özellikleri üzerine etkisi

Dozlar	ÇO (%)	KU (cm)	GU (cm)	KYA (g)**	GYA (g)**	KKA (g)**	GKA (g)**
%0	98.67	4.96	9.18	0.595c	1.528c	0.160bc	0.280c
%25	100.00	5.76	10.79	0.737a	2.127b	0.152b	0.396abc
%50	94.00	5.59	9.52	0.645b	2.173b	0.166c	0.421ab
%75	98.67	5.25	9.48	0.763a	2.526a	0.225a	0.444a
%100	99.33	5.00	8.84	0.688b	1.988b	0.163b	0.368b
Ortalama	***98.13***	***5.31***	***9.56***	***0.686***	***2.068***	***0.173***	***0.382***

**: $p<0.01$; Aynı sütunda aynı harfle gösterilen ortalamalar arasında fark yoktur; ÇO: Çimlenme oranı; KU: kök uzunluğu; GU: Gövde uzunluğu; KYA: Kök yaş ağırlığı; GYA: Gövde yaş ağırlığı; KKA: Kök kuru ağırlığı; GKA: gövde kuru ağırlığı.

Genel olarak değerlendirildiğinde, şerbetçi otu özütü uygulamaları çimlenme oranı, kök uzunluğu ve gövde uzunluğunu istatistiksel olarak etkilemezken, kök ve gövde yaş ve kuru ağırlıkları üzerinde önemli değişikliklere neden olmuştur. Özellikle %75 özüt dozunda tüm biyokütle özelliklerinin en yüksek değerlere ulaşması, bu konsantrasyonun yem bezelyesinin erken fide gelişimi bakımından uygun bir düzey olabileceğini göstermektedir. Bununla birlikte, %100 dozunda biyokütle değerlerinin tekrar azalması, şerbetçi otu özütünün etkisinin konsantrasyona bağlı olduğunu ve yüksek dozlarda gelişim üzerindeki teşvik edici etkinin azalabileceğini ortaya koymaktadır. Bu nedenle şerbetçi otu özütünün yem bezelyesi üzerindeki allelopatik etkisinin daha iyi ortaya konulabilmesi için farklı konsantrasyonların yanı sıra özütte bulunan fenolik bileşikler ve diğer biyolojik aktif maddelerin de birlikte değerlendirilmesi yararlı olacaktır.

4. SONUÇ

Bu çalışmada, farklı konsantrasyonlarda uygulanan şerbetçi otu özütünün yem bezelyesinin çimlenme ve erken fide gelişimi üzerindeki etkileri belirlenmiştir. Özüt dozlarının çimlenme oranı, kök uzunluğu ve gövde uzunluğu üzerindeki etkisi istatistiksel olarak önemsiz bulunurken, kök ve gövde yaş ve kuru ağırlıkları üzerinde istatistiksel olarak önemli farklılıklar oluşturduğu belirlenmiştir. Kök ve gövdeye ait tüm yaş ve kuru ağırlık değerleri %75 özüt dozunda en yüksek seviyeye ulaşmış, %100 dozunda ise yeniden azalmıştır. Bu sonuç, şerbetçi otu özütünün yem bezelyesinin erken dönem biyokütle gelişimini doza bağlı ve doğrusal olmayan şekilde etkilediğini göstermiştir. Sonuç olarak, %75 şerbetçi otu özütü konsantrasyonu, erken fide biyokütlesinin artırılması açısından en uygun doz olarak öne çıkmış; ancak bu etkinin allelokimyasal mekanizmasının ortaya konulması için özütteki biyolojik aktif bileşiklerin ve farklı konsantrasyonların değerlendirildiği ileri çalışmalara ihtiyaç olduğu sonucuna varılmıştır.

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YAZLIK OLARAK YETİŞTİRİLEN MÜRDÜMÜK (LATHYRUS SATIVUS L.) İLE YULAF (AVENA SATIVA L.) KARIŞIMLARININ KURU OT VERİMİ VE KALİTESİ

FORAGE YIELD AND QUALITY OF GRASS PEA (LATHYRUS SATIVUS L.) AND OAT (AVENA SATIVA L.) MIXTURES GROWN UNDER SUMMER CONDITIONS

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ÖZET

Bu çalışma, Bilecik ekolojik koşullarında 2026 yılı yaz yetiştirme döneminde mürdümük (*Lathyrus sativus* L.) ve yulaf (*Avena sativa* L.) karışımlarının ot verimi ve yem kalite özellikleri üzerine etkilerini belirlemek amacıyla yürütülmüştür. Araştırma, tesadüf blokları deneme desenine göre üç tekrarlamalı olarak kurulmuştur. Denemede %100 mürdümük, %75 mürdümük + %25 yulaf, %50 mürdümük + %50 yulaf, %25 mürdümük + %75 yulaf ve %100 yulaf uygulamaları değerlendirilmiştir. Araştırmada kuru ot verimi, ham protein oranı (HP), protein verimi (PV), asit deterjan lif (ADF), nötr deterjan lif (NDF), potasyum (K), kalsiyum (Ca), magnezyum (Mg) ve fosfor (P) içerikleri incelenmiş, elde edilen veriler varyans analizine tabi tutulmuş ve ortalamalar uygun çoklu karşılaştırma testi ile değerlendirilmiştir. Araştırma sonucunda kuru ot veriminin 330.38–804.43 kg da^{-1}, ham protein oranının %11.67–19.50, ham protein veriminin 64.47–93.83 kg da^{-1}, ADF oranının %34.40–40.10, NDF oranının %46.82–58.60, K içeriğinin %2.22–2.65, Ca içeriğinin %0.36–0.95, Mg içeriğinin %0.11–0.16 ve P içeriğinin %0.35–0.45 arasında değiştiği belirlenmiştir. Yulaf oranındaki artış kuru ot verimini artırırken, mürdümük oranındaki artış ham protein ve mineral madde içeriklerinde belirgin iyileşme sağlamıştır. En yüksek kuru ot verimi %100 yulaf uygulamasından, en yüksek ham protein oranı ile Ca, Mg ve P içerikleri ise %100 mürdümük uygulamasından elde edilmiştir. Buna karşın, ham protein verimi bakımından en yüksek değer %25 mürdümük + %75 yulaf karışımında belirlenmiş olup, bu uygulama yüksek biyokütle üretimi ile yeterli ham protein içeriğini bir araya getirmiştir.

Sonuç olarak, tek başına yulaf yetiştiriciliği maksimum kuru ot verimi açısından öne çıkarken, yem kalitesi ve ham protein veriminin birlikte değerlendirildiği durumlarda %25 mürdümük + %75 yulaf karışımının daha dengeli ve sürdürülebilir bir üretim alternatifi sunduğu belirlenmiştir. Bu nedenle, yüksek verim hedeflenen üretim sistemlerinde %100 yulaf, verim ile kalite kriterlerinin birlikte dikkate alındığı yetiştiricilikte ise %25 mürdümük + %75 yulaf karışımı önerilebilir.

Anahtar kelimeler: Mürdümük, yulaf, karışık ekim, protein verimi, yem kalitesi.

ABSTRACT

This study was conducted under the ecological conditions of Bilecik during the 2026 summer growing season to determine the effects of grass pea (*Lathyrus sativus* L.) and oat (*Avena sativa* L.) mixtures on forage yield and quality. The experiment was established according to a randomized complete block design with three replications. Five mixture ratios were evaluated: 100% grass pea, 75% grass pea + 25% oat, 50% grass pea + 50% oat, 25% grass pea + 75% oat, and 100% oat. Dry forage yield, crude protein (CP), crude protein yield (PY), acid detergent fiber (ADF), neutral detergent fiber (NDF), potassium (K), calcium (Ca), magnesium (Mg), and phosphorus (P) contents were determined. Dry forage yield ranged from 330.38 to 804.43 kg da^{-1}, crude protein content from 11.67 to 19.50%, crude protein yield from 64.47 to 88.61 kg da^{-1}, ADF from 34.40 to 40.10%, NDF from 46.82 to 58.60%, K from 2.22 to 2.65%, Ca from 0.36 to 0.95%, Mg from 0.11 to 0.16%, and P from 0.35 to 0.45%. Increasing the proportion of oat significantly enhanced dry forage yield, whereas increasing the proportion of grass pea improved crude protein and mineral contents. The highest dry forage yield was obtained from the sole oat treatment, while the highest crude protein, Ca, Mg, and P contents were recorded in the sole grass pea treatment.

The greatest crude protein yield was achieved with the 25% grass pea + 75% oat mixture, indicating a favorable balance between forage productivity and nutritional quality. The results demonstrated that sole oat cultivation is advantageous for maximizing forage yield, whereas the 25% grass pea + 75% oat mixture provides a more balanced combination of yield and forage quality. Therefore, sole oat is recommended when forage yield is the primary objective, while the 25% grass pea + 75% oat mixture is recommended for sustainable forage production systems where both yield and nutritional quality are considered.
Keywords: Grass pea, oat, intercropping, protein yield, forage quality.

1. GİRİŞ

Mürdümük *(Lathyrus sativus* L.), kuraklık ve olumsuz yetiştirme koşullarına toleransı, yüksek protein içeriği ve farklı ekolojik koşullara uyum yeteneği nedeniyle önemli bir baklagil yem bitkisidir. Bununla birlikte, saf olarak yetiştirildiğinde yatma eğilimi ve bazı dönemlerde düşük kuru madde verimi gibi özellikleri, mürdümüğün tahıllarla birlikte yetiştirilmesini önemli bir alternatif haline getirmektedir. Farklı mürdümük genotiplerinde ot verimi, ham protein, ADF ve NDF gibi yem kalite özelliklerinin önemli ölçüde değişebildiği ve genotiplerin besleme değerleri bakımından farklılık gösterebildiği bildirilmiştir (Başaran ve ark., 2011; Özyazıcı ve Açıkbaş, 2023). Yulaf (*Avena sativa* L.) ise hızlı gelişimi, yüksek biyokütle üretimi ve kaba yem üretimindeki önemi nedeniyle baklagillerle karışık ekimde yaygın olarak kullanılan bir tahıl türüdür. Baklagil ve tahıl türlerinin birlikte yetiştirilmesi, türlerin tamamlayıcı gelişme özelliklerinden yararlanılarak hem verim hem de yem kalitesinin dengelenmesine olanak sağlamaktadır (Anil ve ark., 1998; Caballero ve ark., 1995; Chapko ve ark., 1991). Nitekim tahıl–baklagil karışımlarında türlerin gelişme dönemleri ve morfolojik özelliklerinin birbirini tamamlaması, birim alandan elde edilen yem miktarı ve kalitesinin iyileştirilmesine katkı sağlayabilmektedir (Karadağ ve Büyükburç, 2004).

Mürdümük ve yulafın birlikte yetiştirilmesinde karışım oranı, elde edilen otun verim ve besin değerini belirleyen önemli faktörlerden biridir. Baklagil–buğdaygil karışımlarında uygun karışım oranının belirlenmesi, yüksek biyokütle üretimi ile kaliteli kaba yem elde edilmesi açısından önem taşımaktadır (Uzun ve Aşık, 2012; Okçu ve ark., 2025). Karışımda mürdümük oranının artırılması genellikle ham protein içeriğini yükseltirken, yulaf oranının artması toplam biyokütle ve kuru ot veriminin yükselmesine katkı sağlayabilmektedir. Kırşehir koşullarında yürütülen bir araştırmada, %25 mürdümük + %75 yulaf karışımından en yüksek yaş ot verimi, %50 mürdümük + %50 yulaf karışımından ise en yüksek ham protein verimi elde edilmiş; mürdümük oranının artmasıyla ham protein oranının arttığı, ADF ve NDF oranlarının ise azaldığı bildirilmiştir (Kır ve ark., 2021). Benzer şekilde, mürdümük + tahıl karışımlarında farklı ekim oranlarının silaj verimi ve yem kalitesi üzerinde önemli etkiler oluşturduğu bildirilmiştir (Başaran ve ark., 2018). Mürdümük ile farklı buğdaygil yem bitkilerinin karışımlarını inceleyen güncel çalışmalarda da karışım oranlarının kuru ot verimi ve kalite özellikleri üzerinde belirleyici olduğu ortaya konulmuştur (Yıldıztekin ve Polat, 2025; Yıldıztekin ve Polat, 2026).

Karışık ekimin avantajları yalnızca kuru madde ve ham protein verimiyle sınırlı olmayıp, elde edilen kaba yemin mineral ve genel besleme değerinin iyileştirilmesi açısından da önem taşımaktadır. Nitekim mürdümük genotipleri arasında K, P, Ca ve Mg gibi mineral elementlerin içerikleri bakımından önemli farklılıklar bulunduğu ve mineral kompozisyonunun genotip ile yetiştirme koşullarından etkilenebildiği bildirilmiştir (Başaran ve ark., 2011; Özyazıcı ve Açıkbaş, 2023). Ayrıca, baklagil–yulaf karışımlarında karışım oranı ve hasat döneminin ham protein, ADF, NDF ve diğer yem kalite özelliklerini önemli ölçüde etkilediği bildirilmektedir (Chapko ve ark., 1991; Uzun ve Aşık, 2012; Okçu ve ark., 2025). Bu nedenle, mürdümük ve yulafın farklı oranlarda birlikte yetiştirilmesi; yalnızca yüksek ot veriminin değil, aynı zamanda protein, mineral madde ve lif özellikleri bakımından daha dengeli bir kaba yem elde edilmesi açısından araştırılması gereken önemli bir konudur. Bununla birlikte, yazlık yetiştirme koşullarında mürdümük–yulaf karışımlarının kuru ot verimiyle birlikte ham protein, lif ve mineral madde içerlerinin bir arada değerlendirildiği çalışmaların sınırlı olması, bu konudaki araştırmaların önemini artırmaktadır. Bu çalışma, Bilecik ekolojik koşullarında yazlık olarak yetiştirilen mürdümük ve yulafın farklı karışım oranlarının kuru ot verimi, ham protein, ADF, NDF ve mineral madde içerikleri üzerindeki etkilerini belirlemek amacıyla yürütülmüştür.

2. MATERYAL VE YÖNTEM

Çalışma Bilecik Şeyh Edebali Üniversitesi, Tarımsal Araştırma ve Uygulama arazisinde 2026 vejetasyon döneminde yürütülmüştür. Çalışmada materyal olarak mürdümük (*Lathyrus sativus* L.) "Duduhanım", yulafın (*Avena sativa* L.) "Kahraman" çeşitleri kullanılmış olup, 5 farklı karışım oranı (%100:0, %75:25, %50:50, %25:75 ve %0:100) ele alınmıştır.

Deneme alanının 30 cm derinlikten alınan toprak özelliklerine bakıldığında; toprağın pH'sı 7.85 ve kireç ($CaCO_3$) içeriği %7.45'dir. Ayrıca, toprak 25.38 kg/da fosfor, 125.65 kg/da potasyum ve %1.35 organik madde içeren killi tınlı bünyededir. Çalışmanın yürütüldüğü alanın uzun yıllar ile 2026 yıllarına ait sıcaklık ve yağış miktarları Tablo 1'de verilmiştir. Uzun yıllar sıcaklık ortalaması 15.8 °C iken 2026 yılı 15.6°C olarak tespit edilmiştir. İlin uzun yıllar toplam yağış miktarı 131.5 mm iken 2026 yılı toplam yağış miktarı 199.9 mm olmuştur (Tablo 1).

Table 1. Bilecik ilinin uzun yıllar ile deneme yıllarına ait iklim verileri*

Aylar	Sıcaklık (°C)		Yağış (mm)	
	Uzun yıllar**	2026	Uzun yıllar**	2026
Nisan	11.5	10.7	41.8	67.1
Mayıs	16.1	14.7	47.1	113.1
Haziran	20.0	21.3	42.6	19.7
Ortalama/Toplam	***15.8***	***15.6***	***131.5***	***199.9***

*: Bilecik Meteoroloji Müdürlüğü; **: 1939-2025 yılları arası

Deneme 01.04.2026 tarihinde ve Tesadüf Blokları Deneme Desenine göre, 3 tekrarlamalı olarak kurulmuştur. Ekim el ile yapılmıştır. Denemede sıra arası 30 cm, sıra uzunluğu 4 m olup, parseller 6 sıradan oluşmuştur. Çalışmada dekara tohumluk miktarı mürdümükte 6 kg, yulafta ise 20 kg olarak hesaplanmıştır. Ekim ile birlikte dekara 8 kg fosfor gelecek şekilde DAP gübresi verilmiştir. Hasat işlemi yalın mürdümük ve karışımlarda mürdümüğün tam çiçeklenme, yalın yulafta ise süt olum döneminde yapılmıştır. Her karışım parselinde belirlenen mürdümük ve yulaf kuru ot verimlerinin parselin toplam kuru ot verimine oranlanması ile hesaplanmıştır. Biçim döneminde alınan 500 gram bitki numuneleri etüvde 60 °C'de sabit ağırlığa gelinceye kadar kurutularak tartılmış ve laboratuvarda 1 mm elek çapına sahip değirmende öğütülerek analize hazır duruma getirilmiştir. Öğütülen materyallerin ham protein oranı (HPO), asit deterjanda çözünmeyen lif (ADF), nötr deterjanda çözünmeyen lif (NDF), potasyum (K), fosfor (P), kalsiyum (C) ve magnezyum (Mg) içerikleri Foss NIR Systems Model 6500 Win ISI II v1.5 cihazında IC-0904-FE kalibrasyon programı kullanılarak belirlenmiştir.

3. BULGULAR VE TARTIŞMA

Karışım oranlarının kuru ot verimi, ham protein oranı (HPO), ADF ve NDF içerikleri üzerine etkisi önemli ($p<0.01$) bulunmuştur (Tablo 2). Kuru ot verimi 330.38–804.43 kg da^{-1} arasında değişmiş ve en yüksek değer %100 yulaf uygulamasında belirlenmiştir. Yulaf oranındaki artışla kuru ot veriminin yükselmesi, yulafın yüksek biyokütle oluşturma kapasitesiyle açıklanabilir. Buna karşılık HPO, mürdümük oranının artmasıyla yükselmiş ve %100 mürdümükte %19.50 ile en yüksek değere ulaşmıştır. Başaran ve ark. (2011), mürdümük genotiplerinde HPO'nun %20.95–26.31 arasında değiştiğini ve mürdümüğün yüksek proteinli bir yem bitkisi olduğunu bildirmiştir. Benzer şekilde, Özyazıcı ve Açıkbaş (2023) farklı mürdümük genotiplerinde HPO'nun %22.30–25.78 arasında değiştiğini bildirmiştir. Mevcut çalışmada yulaf oranının artmasıyla HPO'nun azalması, karışımda yüksek proteinli baklagilin payının azalmasına bağlanabilir. Protein verimi açısından ise yüksek biyokütle üretiminin etkisi belirgin olmuş ve en yüksek değer %100 yulafta 93.83 kg da^{-1}, %25 mürdümük + %75 yulaf karışımında ise 88.61 kg da^{-1} olarak belirlenmiştir. Bu sonuç, yalnızca ham protein oranının değil, kuru ot veriminin de birim alandan elde edilen protein miktarını belirlediğini göstermektedir. Dolayısıyla %100 yulaf maksimum kuru ot ve protein verimi açısından, %100 mürdümük ise protein, lif ve mineral kalite açısından öne çıkarken; %25 mürdümük + %75 yulaf karışımı verim ve yem kalitesini birlikte değerlendiren üretim sistemleri için daha dengeli bir seçenek olarak değerlendirilebilir. ADF ve NDF içerikleri de yulaf oranının artmasıyla yükselmiş; en yüksek değerler %100 yulafta sırasıyla %40.10 ve %58.60 olarak belirlenmiştir. Buna karşılık saf mürdümükte ADF (%34.40) ve NDF (%46.82) daha düşük bulunmuştur.

Başaran ve ark. (2011), mürdümük genotiplerinde ADF ve NDF değerlerini sırasıyla %28.80–34.40 ve %33.42–45.01 olarak bildirmiştir. Bu sonuç, mevcut çalışmada mürdümük oranının artırılmasının lif içeriği bakımından daha kaliteli bir yem materyali oluşturduğunu göstermektedir.

Tablo 2. Karışımların yem verimi ile bazı kalite özellikleri

Karışımlar	KOV (kg/da)**	HPO (%)**	PV (kg/da)**	ADF (%)**	NDF (%)**
%100M	330.38e	19.50a	64.47	34.40e	46.82e
%100Y	804.43a	11.67e	93.83	40.10a	58.60a
%75M+25Y	417.15d	17.74b	74.02	35.83d	49.77d
%50M+50Y	533.64b	15.59c	83.19	37.25c	52.71c
%25M+75Y	650.14c	13.63d	88.61	38.68b	55.66b
Ortalama	***547.15***	***15.62***	***80.82***	***37.25***	***52.71***

**: p<0.01; Aynı sütunda aynı harfle gösterilen ortalamalar arasında fark yoktur. M: Mürdümük; Y: Yulaf; KOV: Kuru ot verimi; HPO: Ham protein oranı: PV: Protein verimi; ADF: Asit deterjanda çözünmeyen lif; NDF: Nötr deterjanda çözünmeyen lif.

Tablo 3. Karışımların besin içerikleri

Karışımlar	K (%)**	P (%)**	Ca (%)**	Mg (%)**
%100M	2.65a	0.45a	0.95a	0.16a
%100Y	2.21e	0.35e	0.36e	0.11d
%75M+25Y	2.54b	0.43b	0.80b	0.15ab
%50M+50Y	2.43c	0.40c	0.66c	0.14bc
%25M+75Y	2.32d	0.38d	0.51d	0.13cd
Ortalama	***2.43***	***0.40***	***0.66***	***0.14***

**: p<0.01; Aynı sütunda aynı harfle gösterilen ortalamalar arasında fark yoktur. M: Mürdümük; Y: Yulaf; K: Potasyum; P: Fosfor; Ca: Kalsiyum; Mg: Magnezyum.

Karışım oranlarının K, P, Ca ve Mg içerikleri üzerindeki etkisi önemli (p<0.01) bulunmuştur (Tablo 3). Tüm besin elementlerinde en yüksek değerler %100 mürdümük, en düşük değerler ise %100 yulaf uygulamasında belirlenmiş ve mürdümük oranının azalmasına bağlı olarak mineral içerikleri düzenli şekilde azalmıştır. Potasyum içeriği %2.21–2.65 arasında değişmiş ve %100 mürdümükte %2.65 ile en yüksek değere ulaşmıştır. Bu değer, Özyazıcı ve Açıkbaş (2023) tarafından mürdümük genotiplerinde bildirilen %2.13–2.46 ve Başaran ve ark. (2011) tarafından bildirilen %1.67–2.33 aralıklarıyla genel olarak uyumludur. Fosfor içeriği %0.35–0.45 arasında değişirken, %100 mürdümükte belirlenen %0.45 değerinin Özyazıcı ve Açıkbaş (2023) tarafından bildirilen %0.393–0.427 aralığıyla büyük ölçüde örtüştüğü görülmüştür. Kalsiyum içeriği %0.36–0.95 arasında değişmiş ve saf mürdümükte belirlenen %0.95 değeri, Özyazıcı ve Açıkbaş (2023)'ın bildirdiği %1.267–1.378 değerlerinden düşük olmakla birlikte, Başaran ve ark. (2011)'nın sonuçlarıyla karşılaştırılabilir düzeyde bulunmuştur. Magnezyum içeriği ise %0.11–0.16 arasında değişmiş ve en yüksek değer %100 mürdümükte belirlenmiştir; bu değer Özyazıcı ve Açıkbaş (2023) tarafından bildirilen %0.230–0.257 aralığından daha düşük bulunmuştur. Literatürdeki farklılıkların genotip, yetiştirme koşulları ve hasat döneminden kaynaklanabileceği düşünülmektedir. Genel olarak değerlendirildiğinde, K, P, Ca ve Mg içeriklerinin mürdümük oranındaki artışla yükselmesi, mürdümüğün mineral madde bakımından yulafa göre daha zengin olduğunu ve karışımlarda mürdümük oranının artırılmasının mineral besleme değerini olumlu yönde etkilediğini göstermektedir**.**

4. SONUÇ

Sonuç olarak, yazlık koşullarda mürdümük ve yulafın farklı oranlarda karışık ekilmesi, kuru ot verimi ile kalite özellikleri üzerinde önemli farklılıklar oluşturmuştur.

Yulaf oranının artırılması kuru ot verimini yükseltirken, mürdümük oranının artması ham protein ve mineral madde içeriğini iyileştirmiş, ayrıca ADF ve NDF oranlarının daha düşük düzeylerde kalmasını sağlamıştır. Bu sonuçlar, mürdümük ve yulafın birlikte yetiştirilmesinin yalnızca verim açısından değil, elde edilen kaba yemin besleme değerinin iyileştirilmesi açısından da avantaj sağlayabileceğini göstermektedir. Buna göre; Bilecik ekolojik koşullarında yazlık kaba yem üretiminde kuru ot verimi ve kalitesinin birlikte hedeflendiği durumlarda %25 mürdümük + %75 yulaf karışımının tercih edilebileceği sonucuna varılmıştır.

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BACTERIAL DEGRADATION OF LOW DENSITY POLYETHYLENE

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Abstract
Bacteria isolated from dumpsites in Ibadan, Oyo State, Nigeria were screened for their potentials in the degradation of low density polyethylene (Sachet Water Nylon Waste).The nylon was pulverized and used as the only source of carbon in the mineral salt media used in the study. The soil samples collected were enriched on MSM for three days; isolation was done using spread plate technique after serial dilution. Pure isolates were screened for their ability to utilize Low Density Polyethylene (LDPE) using clear zone technique. Isolates with clearer zone formations were selected and used for the degradation study in the laboratory and field. The extent of degradation was determined using weight loss and functional groups changes using Fourier Transform Infrared (FTIR) analysis. The selected isolates were characterized and molecular identification was done using 16Sr DNA sequencing. A total of forty-three bacteria isolates were obtained from Lapite, Ajakanga and Awoton dumpsites: four bacteria isolates with clearer zone formations were used for the biodegradation study (laboratory and field). The SWNW showed loss of weight in the laboratory (between 22.10%-26.10% for isolates Aj7 and La25, respectively) while in the field (between 16.30%-17.90% for isolates Aj7 and La25, respectively). The FTIR result showed appearance of new peaks of carbonyl group at 1732cm^{-1} and 1728cm^{-1} for SWNW treated with isolates Aj5 and La25 in the laboratory respectively, while in the field at 1747cm^{-1} and 1732cm^{-1} for isolates Aw9 and Aj7 respectively. The isolates were identified as *Pseudomonas aeruginosa* PZ245419 Aj5, *Lysinibacillus sphaericus* PZ245418 Aj7, *Lysinibacillus fusiformis* PZ245415 Aw9 and *Lysinibacillus fusiformis* PZ245417 La25. The of weight of SWNW with the formation of new peaks, disappearance of old peaks, more concentrations of functional groups and shifts in the peak of the functional groups from FTIR are evidence of degradation potential of the isolates used in this study.

SHARED GENETIC ARCHITECTURE AND CAUSAL EFFECTS OF CIRCULATING VITAMIN D ON CARDIOMETABOLIC DISEASES: EVIDENCE FROM LINKAGE DISEQUILIBRIUM SCORE REGRESSION AND MENDELIAN RANDOMIZATION

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ABSTRACT

Background

Epidemiological studies have reported inverse associations between circulating vitamin D levels and cardiometabolic diseases, however these association may be influenced by confounding and reverse causation. This study investigated the genetic correlation between vitamin D levels and Type 1 diabetes (T1D), Type 2 diabetes (T2D), Myocardial Infarction (MI), Heart failure (HF), Coronary artery disease (CAD), and hypertension, and estimated the causal effect of vitamin D levels on these cardiometabolic outcomes using genetic epidemiological methods.

Methods

Genome-wide genetic correlation between vitamin D levels (n = 417,580) and diabetes (T1D; n = 520,580, T2D; n = 898,130) and cardiometabolic traits (MI; n = 461,823, HF; n = 977,323, CAD; n = 547,261, Hypertension; n = 484,598) were estimated using linkage disequilibrium score regression (LDSC). Summary statistics for T2D were obtained from the DIAGRAM Consortium, whereas other phenotypes were retrieved from the GWAS Catalog. Then, two-sample Mendelian randomization (MR) analyses were performed using independent SNPs ($P < 5 \times 10^{-8}$; $r^2 < 0.001$) associated with circulating 25-hydroxyvitamin D [25(OH)D] levels as instrumental variables to assess the potential causal relationships between vitamin D levels and cardiometabolic outcomes. Causal effects were estimated using inverse-variance weighting (IVW), weighted median, MR-Egger, MR-PRESSO, and generalized summary-data-based Mendelian randomization (GSMR) methods.

Results

A significant genetic correlation was identified in LDSC analysis between vitamin D levels with T1D (rg = -0.18, P = 0.024), MI (rg = -0.10, P = 0.012), and CAD (rg = -0.09, P = 0.009), however, with T2D genetic relation was negative but not statistically significant (rg = −0.19, P = 0.20). Mendelian Randomization analyses demonstrated evidence of a protective causal effect of higher genetically predicted vitamin D levels on MI (IVW OR = 0.78, P = 0.007; GSMR OR = 0.96, P = 0.001). A suggestive protective causal association was observed between vitamin D levels and T2D risk, with consistent results in sensitivity analyses (weighted median OR = 0.89, P = 0.016; GSMR OR = 0.68, P = 1.6×10^{-5}). No consistent evidence of a causal association was observed between vitamin D levels and HF, T1D, CAD, or hypertension.

Conclusions

These findings provide genetic evidence suggesting that higher vitamin D levels may have protective causal effects against T2D and MI. Therefore, vitamin D may represent a potentially modifiable target for the prevention of selected cardiometabolic diseases. Further investigations are warranted to clarify the underlying biological mechanisms and determine whether vitamin D supplementation has potential clinical benefits.

PROTECTION OF HUMAN LIFE AND HEALTH IN THE CONTEXT OF CONSTRUCTION-RELATED OFFENSES: AN INTERDISCIPLINARY APPROACH

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Abstract
The protection of human life and health represents a fundamental objective of criminal law, particularly in the context of construction activities, where violations of legal and technical requirements may generate serious risks to workers, residents, and third parties. Construction-related offenses are characterized by a complex interaction between legal, technical, organizational, economic, and social factors, which makes their analysis from a purely criminal-law perspective insufficient. This article examines the protection of life and health in the context of construction-related offenses through an interdisciplinary approach integrating criminal law, criminology, construction engineering, occupational safety, and public administration.
The research aims to identify the main criminal-law mechanisms for preventing and sanctioning conduct that endangers life and health in the construction sector, as well as the factors contributing to the occurrence of such offenses. Particular attention is given to violations of construction standards, unauthorized or defective works, failure to comply with occupational safety requirements, negligent conduct by responsible persons, and deficiencies in supervision and administrative control. The study also examines the relationship between individual criminal liability and institutional or organizational failures within the construction process.
The methodology combines doctrinal and normative legal analysis with criminological approaches and an interdisciplinary assessment of construction safety risks. The research demonstrates that effective protection of life and health requires not only appropriate criminal sanctions but also preventive mechanisms, effective technical supervision, professional accountability, risk assessment, and interinstitutional cooperation. The article argues that strengthening prevention, improving the evidentiary framework, ensuring qualified technical expertise, and enhancing the effectiveness of public oversight can significantly contribute to reducing construction-related risks and improving the protection of fundamental human rights.
Keywords: construction-related offenses; criminal liability; protection of human life and health; occupational safety; interdisciplinary approach.

ROLE OF PUBLIC HEALTH AUTHORITIES IN PREVENTING CONSTRUCTION-RELATED OFFENSES IN THE REPUBLIC OF MOLDOVA

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Abstract
Construction-related offenses represent a complex category of unlawful acts that may endanger human life and health, particularly when violations of construction, occupational safety, sanitary, and public health requirements occur. In the Republic of Moldova, the prevention of such offenses requires not only effective criminal-law mechanisms but also coordinated action by public authorities responsible for health protection and safety. This study examines the role of public health authorities in preventing construction-related offenses, focusing on their regulatory, preventive, supervisory, and interinstitutional functions.
The research aims to identify the mechanisms through which public health authorities can contribute to reducing risks associated with construction activities and to assess the effectiveness of existing preventive measures. Particular attention is given to sanitary and epidemiological requirements, occupational health, assessment of environmental and health risks, monitoring of construction sites, and cooperation with local public authorities, construction supervision bodies, law-enforcement institutions, and judicial experts.
The methodology combines legal-dogmatic, comparative, systemic, and interdisciplinary approaches, complemented by an analysis of the Moldovan regulatory framework and relevant institutional practices. The study demonstrates that effective prevention cannot be limited to post factum criminal prosecution. Early identification of health and safety risks, systematic inspections, exchange of information between institutions, digitalization of monitoring mechanisms, and clear allocation of institutional responsibilities can significantly contribute to preventing offenses and protecting workers, residents, and other persons exposed to construction-related risks.
The article concludes by proposing measures aimed at strengthening institutional cooperation, improving preventive supervision, enhancing data exchange, and integrating public health considerations into the broader system for preventing and combating construction-related offenses in the Republic of Moldova.
Keywords: public health authorities; construction-related offenses; prevention; occupational health and safety, construction sector.

FIRTH'S PENALIZED-LIKELIHOOD REGRESSION FOR HANDLING SEPARATION IN HYPERTENSION RISK FACTOR DATA: EVIDENCE FROM BIRNIN KEBBI, NIGERIA

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ABSTRACT
Logistic regression is the standard analytical technique for modelling binary clinical outcomes, but its maximum-likelihood estimator becomes unreliable under complete or quasi-complete separation, a condition in which a predictor near-perfectly distinguishes the outcome categories, leading to inflated coefficients, artificially large standard errors and misleadingly wide confidence intervals. This study demonstrates and corrects this problem using a hospital-based cross-sectional dataset of 150 patients attending the Federal Teaching Hospital, Birnin Kebbi, Nigeria, in which hypertension status was modelled as a function of age, body mass index (BMI), fasting blood glucose concentration, gender and family history of hypertension. Standard binary logistic regression, estimated via iteratively reweighted least squares, converged but exhibited a clear symptom of quasi-complete separation in the family history predictor, for which only 6 of 68 patients with a positive family history were non-hypertensive: the adjusted odds ratio (AOR) for family history was 21.40 with an extremely wide 95% confidence interval (3.63–126.07). Firth's penalized-likelihood method, which augments the likelihood function with a Jeffreys invariant-prior penalty, was applied to the same model. The Firth-corrected model produced a shrunken, more defensible adjusted odds ratio of 14.22 (95% CI: 2.95–68.55), representing an approximately 46 percent reduction in confidence interval width, while age, BMI, fasting blood glucose and gender estimates were similarly stabilised. Model fit remained excellent and virtually unchanged (Nagelkerke R^2 = 0.836 for the standard model versus 0.834 for the Firth model; classification accuracy of 92.0 percent for both). These findings illustrate that Firth's method preserves the substantive clinical conclusions of a standard logistic regression analysis while providing materially more credible interval estimates when sparse, highly predictive binary covariates are present, and they offer a practical, replicable template for researchers in resource-constrained clinical settings working with modest sample sizes.

Keywords: Firth's penalized likelihood; quasi-complete separation; logistic regression; hypertension; sparse-data bias; biostatistics; Nigeria

ADVANCED ENGINEERING SOLUTIONS FOR NEXT-GENERATION HEALTHCARE AND HEALTH SCIENCE APPLICATIONS

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Abstract
Advanced engineering solutions have become increasingly important for enhancing the performance of medical devices, diagnostic technologies, patient support systems, and the healthcare infrastructure. Still, the combination of engineering design, computational modelling, materials selection and health-science requirements is fragmented, restricting technological performance, reliability, cost, and sustainability. To fill these needs, this study aims to provide the integration of advanced design, materials, digital technologies and performance optimization within an engineering framework that will interface with healthcare and health-science application. The main objective of the study is to create an integrated engineering solution for the design, dependability, efficiency and sustainability enhancement of next generation healthcare and health-science technologies. Using CAD-based design, materials selection, FEA, computational modelling, and performance optimization, a multidisciplinary engineering approach was established. Medical devices, healthcare equipment, and patient-support technologies were selected as a representative group of technologies for assessment, and the structural performance, deformation, reliability, energy consumption, material utilization, and operational efficiency indicators were used to assess the technologies. A multi-objective optimization approach was utilized to determine engineering designs that Favor technical efficiency, resource efficiency, and healthcare. The optimized engineering configuration highlights the improvement by 25.7% in material utilization, 18.6% in maximum deformation and 29.3% in overall system performance as compared with the conventional engineering designs. Energy use went down by 21.4%, and estimated reliability of operation went up 23.8%. Also, the integrated framework yielded improved technical performance and sustainability with an estimated reduction in environmental impact of 20.6%. The results illustrate the significant benefits that can be achieved by a multidisciplinary engineering design, computational modelling, materials optimization, and health-science approach to generate more reliable, efficient, sustainable and high-performing solutions to next-generation healthcare technologies.
Keywords: Healthcare Engineering; Health Sciences; Medical Devices; CAD Design; Engineering Optimization; Sustainable Healthcare.

SOLVENT-DEPARTDENT ANTIBACTERIAL ACTIVITY OF TURTEMIC (CURCUMA LONGA) EXTRACTS AGAINST KLEBSIELLA PNEUMONIAE AND STAPHYLOCOCCUS AUREUS

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ABSTRACT

Microorganisms remain a major global health concern, due to the increasing emergence of antimicrobial resistance. This has intensified the search for effective antibacterial agents from natural sources. Turmeric is a medicinal plant with considerable therapeutic potential.

Aim

The study evaluated the antibacterial activity of aqueous, ethanol, n-hexane and chloroform extracts of C. longa against *Staphylococcus aureus* and *Klebsiella pneumoniae*.

Method

The agar disc diffusion method was employed to evaluate antibacterial susceptibility. While the minimum inhibitory concentration (MIC) and minimum bactericidal concentrations (MBC) were determined using broth dilution techniques.

Findings

The ethanol extract demonstrated the highest antibacterial activity against both bacteria, *S. aureus*, with an inhibition zone of 11.7 ± 2.0 mm at 200 mg/mL, and Klebsiella *pneumoniae* producing an inhibition zone of 23.8 ± 2.7 mm at 200 mg/mL. The MIC of *S. aureus* was 25 mg/mL for the ethanol extract, 100 mg/mL for the n-hexane and chloroform extracts, and 200 mg/mL for the aqueous extract. For *K. pneumoniae*, the MIC was approximately 25 mg/mL for the ethanol and chloroform extracts, while the aqueous and n-hexane extracts exhibited MIC values within the 25–50 mg/mL range. The MBC values against *S. aureus* were 100 mg/mL for n-hexane, 50 mg/mL for aqueous, and 100 mg/mL for both ethanol and chloroform extracts. Against *K. pneumoniae*, MBC values were 200 mg/mL for n-hexane and chloroform extracts 100 mg/mL for ethanol extract, while no bactericidal activity was observed with the aqueous extract within the tested concentration range.

Conclusion

The findings demonstrate that the antibacterial activity of C. longa varies according to the extraction solvent and bacterial species, with ethanol extract showing the strongest overall antibacterial potential, particularly against *K. pneumoniae*. These results highlight C. longa as a promising natural source of antibacterial compounds and warrant further investigation of its bioactive constituents.

Keywords: Turmeric, Antibacterial susceptibility, MIC, MBC

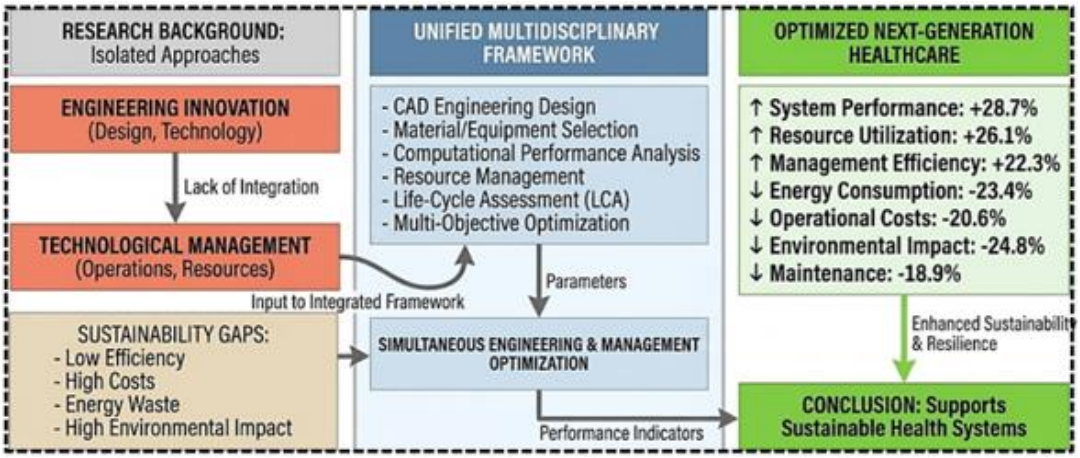
INTEGRATED ENGINEERING AND MANAGEMENT SOLUTIONS FOR SUSTAINABLE NEXT-GENERATION HEALTHCARE AND HEALTH SCIENCE SYSTEMS

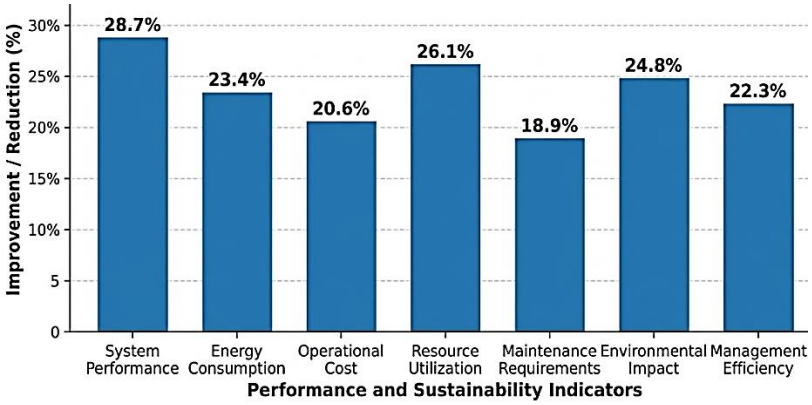
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ABSTRACT
Sustainable healthcare systems are increasingly demanding integration of engineering innovation, technological management, resource optimization and health-science requirements. However, engineering and management approaches are often developed in silos, leading to breaks in efficiency, cost control, energy use, technological reliability and environmental sustainability in the healthcare system. This study aims to fill these gaps by jointly developing engineering solutions and management strategies within a unified framework for sustainable next-generation healthcare and health-science systems. The study is aimed at developing an integrated engineering management framework for improving healthcare-system performance, resource efficiency, operational management, technological reliability, cost-effectiveness and environmental sustainability. The multidisciplinary framework that was developed includes life-cycle assessment (LCA), multi-objective optimization, computational performance analysis, resource management, materials and equipment selection, and CAD-based engineering design. Healthcare technology and infrastructure components were evaluated using technical performance, energy consumption, operating cost, maintenance requirements, resource utilization, and environmental impact factors. Engineering and managerial elements were simultaneously adjusted to develop sustainable system designs. The Sustainable optimized framework improved overall healthcare-system performance by 28.7%, reduced energy consumption by 23.40%, and decreased operational costs by 20.6% compared with conventional configurations. Resource utilization efficiency increased by 26.10%, while maintenance requirements decreased by 18.90%. The optimized system also achieved a 24.8% reduction in estimated environmental impact and a 22.30% improvement in overall management efficiency.

GRAPHICAL ABSTRACT





The findings indicate that integrating technical innovation with managerial optimization may enhance healthcare performance, reduce operating and environmental expenses, and foster the development of more efficient, resilient, and sustainable next-generation healthcare and health-science systems.

Keywords: Healthcare Engineering; Engineering Management; Sustainable Healthcare; Health Sciences; System Optimization; Medical Technology.

ENHANCING NUTRITIONAL QUALITY OF CASSAVA MAHEWU: A FUNCTIONAL BEVERAGE TO COMBAT

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Abstract
Micronutrient deficiencies are a major public health concern in Sub-Saharan Africa, with Mozambique reporting high rates of childhood stunting and widespread iron and vitamin A deficiencies. Cassava (Manihot esculenta), a staple crop, is low in protein and essential micronutrients. Mahewu, a traditional fermented cassava beverage, offers a culturally acceptable platform for nutritional enhancement. This study evaluated the fortification of cassava mahewu (200 mL) with carrot (20 g) and beetroot (7.5 g), individually and in combination. Proximate composition, mineral content, vitamin C, physicochemical properties, and sensory attributes were assessed. Fortified mahewu showed significant reductions in moisture (90.28-88.67%) and carbohydrates (8.40-2.45%) and notable increases in protein (0.50-3.47%), ash (0.36-2.52%), dietary fiber (0.41-2.83%), vitamin C (3.13-7.20%), iron (0.94-8.15 mg/L), calcium (37.43-66.63 mg/L), magnesium (0.047-0.109 mg/L), potassium (155.67-543.67 mg/L), and zinc (0.10-0.46 mg/L). Fat content and water activity were largely unaffected. Sensory evaluation revealed high acceptability for all fortified samples, with the combined carrot-beetroot formulation scoring highest for taste, aroma, viscosity, and overall acceptability. The findings indicate that fortifying cassava mahewu with carrot and beetroot significantly improves its nutritional value without compromising sensory quality. This approach offers a practical, sustainable functional food strategy to address micronutrient deficiencies and enhance dietary diversity in cassava-dependent populations.
Keywords : Cassava mahewu, micronutrients deficiencies, Mozambique

DOSE-RELATED DIFFERENCES IN HEMATOLOGICAL AND BIOCHEMICAL MARKERS AMONG CANNABIS–TOBACCO USERS IN MOROCCO

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Abstract
Cannabis is frequently consumed with tobacco in Morocco, yet evidence regarding the hematological and biochemical alterations associated with chronic co-use remains limited. This study investigated blood parameter variations associated with cannabis–tobacco joint consumption among young men from the Beni Mellal region, Morocco. Thirty male participants were allocated to three groups (n = 10 each): non-users (controls), moderate users (2-5 joints/day), and heavy chronic users (15-22 joints/day). Fasting blood samples were analyzed for hematological indices, leukocyte profiles, lipid parameters, renal biomarkers, and hepatic aminotransferases. Heavy users exhibited significantly lower red blood cell counts (5.046 vs. 5.658 M/mm^3; $P < 0.0001$), hemoglobin concentrations (15.16 vs. 16.42 g/dL; $P = 0.0015$), and hematocrit (44.64 vs. 48.17%; $P = 0.0004$) than controls. Platelet counts were also reduced in heavy users (235,600 vs. 267,900/mm^3; $P = 0.0109$), whereas eosinophil counts increased markedly. Heavy consumption was further associated with lower total cholesterol (1.41 vs. 1.69 g/L), triglycerides, urea, SGOT, and SGPT, while creatinine concentrations increased among users. Overall, chronic heavy cannabis–tobacco co-use was associated with distinct hematological and biochemical alterations, particularly affecting erythrocyte indices, platelets, lipid metabolism, and renal and hepatic biomarkers. These findings suggest a consumption-related biological response; however, the limited sample size and potential nutritional and lifestyle confounding warrant cautious interpretation and validation in larger, well-controlled studies.
Keywords: cannabis; hashish; tobacco; hematological parameters; biochemical markers; chronic consumption; Morocco

COMPARATIVE ANALYSIS OF GI ABSORPTION PROPERTIES OF THREE HYDRAZONE DERIVATIVES USING THE SWISSADME PLATFORM

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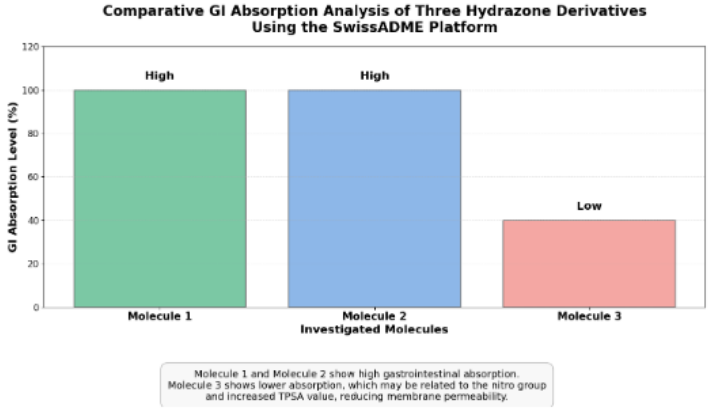
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ABSTRACT
In this thesis, the gastrointestinal absorption properties of three hydrazone derivatives were comparatively investigated using the SwissADME platform. Gastrointestinal absorption is one of the important pharmacokinetic parameters used to evaluate the oral bioavailability potential of drug-like compounds. According to the SwissADME results, Molecule 1 and Molecule 2 showed high GI absorption, while Molecule 3 demonstrated low GI absorption. The difference in absorption behavior may be associated with structural variations among the investigated compounds. In particular, the presence of the nitro group in Molecule 3 increases the polarity of the molecule and leads to a higher TPSA value. A high topological polar surface area can negatively affect membrane permeability and reduce the ability of the compound to pass through biological membranes. In contrast, Molecule 1 and Molecule 2 showed more favorable gastrointestinal absorption profiles. Their physicochemical parameters appear to be more suitable for oral absorption. Therefore, these two compounds may be considered more promising candidates for further pharmacokinetic and biological studies. Overall, the SwissADME results indicate that Molecule 1 and Molecule 2 have better oral absorption potential, whereas Molecule 3 has relatively limited absorption capacity. This comparison shows that substituent groups play an important role in determining the ADME behavior of hydrazone derivatives.



Keywords: SwissADME, GI absorption, hydrazone derivatives, TPSA, oral absorption, pharmacokinetics.

MOLECULAR DOCKING INVESTIGATION OF (E)-4-HYDROXY-N′-(3-IODO-5-METHOXY-4-((5-NITROFURAN-2-YL)OXY)BENZYLIDENE)BENZOHYDRAZIDE AGAINST THE 4KFG PROTEIN TARGET

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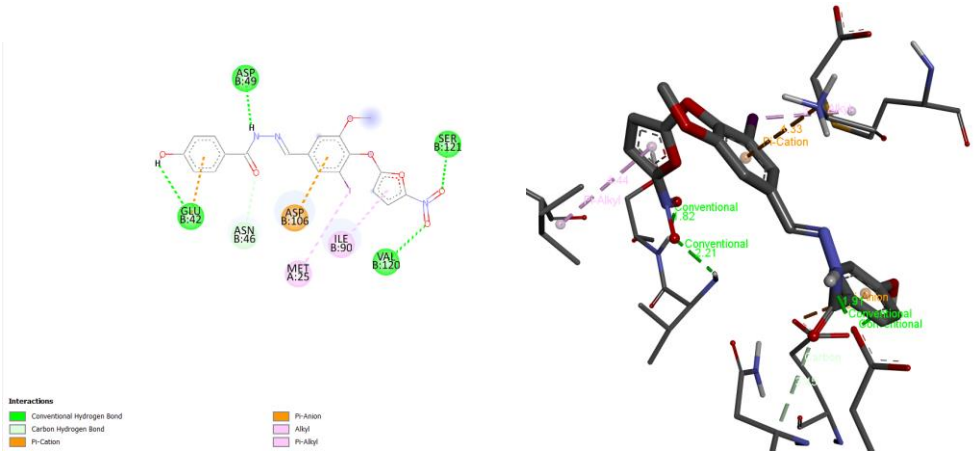
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ABSTRACT
Molecular docking is widely used as an in silico approach to investigate the binding behavior of bioactive compounds toward selected protein targets and to characterize the molecular interactions responsible for ligand recognition. In the present study, the binding profile of (E)-4-hydroxy-N′-(3-iodo-5-methoxy-4-((5-nitrofuran-2-yl)oxy)benzylidene)benzohydrazide (C52) was investigated against the 4KFG protein target using a molecular docking approach. Analysis of the predicted binding pose revealed that the compound was accommodated within the binding region through a combination of hydrogen-bonding, π-mediated, and hydrophobic interactions. Conventional hydrogen bonds were observed with Asp49, Val120, and Ser121, while an additional interaction involving the hydroxyl functionality was detected with Glu42. The aromatic system of the ligand contributed to its stabilization through π-mediated interactions involving Glu42 and Asp106, whereas hydrophobic alkyl/π-alkyl contacts were associated mainly with Met25 and Ile90. Additional contacts involving Asn46 were also identified within the binding environment. The coexistence of polar and hydrophobic interactions indicates complementary recognition of the ligand within the 4KFG binding region. In particular, the hydrazone-related functionality, aromatic rings, and oxygen-containing substituents provide multiple interaction sites capable of participating in ligand–protein recognition. These findings suggest that C52 exhibits a favorable interaction pattern with the 4KFG protein target and may represent an interesting molecular scaffold for further computational and experimental investigation.

However, molecular dynamics simulations and experimental biological studies are required to confirm the stability and biological relevance of the predicted binding mode.



Keywords: Molecular docking; 4KFG; hydrazone derivative; protein–ligand interactions; hydrogen bonding; in silico analysis; nitrofuran derivative

PREVALENCE OF MALARIA INFECTION DURING PREGNANCY: A SYSTEMATIC LITERATURE REVIEW

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ABSTRACT
Malaria during pregnancy remains a major public health challenge, particularly in malaria-endemic regions, where it contributes substantially to maternal and neonatal morbidity and mortality. This systematic review synthesized current evidence on the prevalence of malaria infection during pregnancy and its associated maternal outcomes. A systematic search of Google Scholar, PubMed, CrossRef, Scopus, ScienceDirect, Web of Science, and ProQuest was conducted to identify studies published between 2012 and 2026. Eligible studies reported malaria prevalence among pregnant women, diagnostic methods, and associated outcomes. Following screening and eligibility assessment, 38 studies conducted across Africa, Asia, and South America were included.The included studies comprised predominantly cross-sectional designs with sample sizes ranging from 50 to 5,196 participants. Malaria prevalence varied markedly across countries, ranging from 2.0% to 91.6%, with the highest burden reported in several sub-Saharan African settings, particularly Nigeria, Ghana, and Ethiopia. *Plasmodium falciparum* was the predominant infecting species. Microscopy, rapid diagnostic tests, and polymerase chain reaction were the principal diagnostic methods. Anemia was consistently associated with malaria infection, with prevalence ranging from 6.0% to 91.5%, and malaria-positive women experienced significantly higher anemia rates than uninfected women. Considerable heterogeneity in prevalence reflected differences in transmission intensity, diagnostic approaches, geographical settings, and implementation of preventive interventions. Malaria during pregnancy remains highly prevalent, particularly in sub-Saharan Africa, and continues to pose serious risks to maternal health. Strengthening antenatal malaria prevention through improved coverage of intermittent preventive treatment, insecticide-treated nets, prompt diagnosis, and integrated anemia management is essential. Further longitudinal and molecular epidemiological studies are required to improve surveillance and optimize prevention strategies.
Keywords: Malaria in pregnancy; pregnant women; Malaria prevalence; Maternal anemia; Antenatal care; Systematic review.

CLIMATE CHANGE AWARENESS AND SUSTAINABILITY PRACTICES AMONG UNDERGRADUATE STUDENTS OF FEDERAL UNIVERSITY GUSAU, ZAMFARA STATE, NIGERIA

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Abstract
Climate change is increasingly recognised as a major environmental challenge requiring adequate awareness and responsible sustainability practices among young people. This study examined climate change awareness and sustainability practices among undergraduate students of Federal University Gusau, Zamfara State, Nigeria. Three objectives, two research questions and one null hypothesis guided the study. The study adopted a correlational survey design. The population comprised 6,799 undergraduate students, from which a sample of 365 students was selected using the Research Advisors sample-size table. Data were collected using a structured questionnaire covering climate change awareness and sustainability practices. Mean and standard deviation were used to answer the research questions, while Pearson Product Moment Correlation was used to test the hypothesis at the 0.05 level of significance. The findings showed that undergraduate students demonstrated a high level of climate change awareness, with a grand mean of 3.42 (SD = 0.65). The students also demonstrated a high level of sustainability practices, with a grand mean of 3.35 (SD = 0.69). The result further revealed a significant positive relationship between climate change awareness and sustainability practices ($r = 0.624$, $p < .001$). The null hypothesis was therefore rejected. The study concluded that higher climate change awareness was associated with higher levels of reported sustainability practices among the students. It recommended strengthening climate change education, environmental awareness programmes, recycling and reuse initiatives, and practical sustainability activities within the university.
Keywords: Climate Change Awareness; Environmental Education; Sustainability Practices; Undergraduate Students; University Education.

BIOMEDICAL APPLICATIONS OF FUCOSYLATED HUMAN MILK OLIGOSACCHARIDES

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Abstract
Breastfeeding is considered the gold standard for infant nutrition. However, there are certain medical situations, such as drug exposure, infection risk, or anatomical challenges, where breastfeeding may not be advisable or possible. While conventional infant formulas provide essential macronutrients (proteins, carbohydrates, and fats) and micronutrients (vitamins and minerals), they often lack important bioactive compounds that are present in breast milk, such as human milk oligosaccharides (HMOs). More than 200 different oligosaccharides have been discovered in breast milk, with nearly half of them being fucosylated. The 2′-fucosyllactose (2′-FL) and 3-fucosyllactose (3-FL) are particularly important for the nutrition and development of newborns. The purpose of this study is to summarize the primary effects of these complex biomolecules on infant health and development. Interestingly, HMOs pass through the gut and intestines undigested, which means they do not directly provide nutrition to newborns. However, these compounds support infant health in several other significant ways. Both 2′-FL and 3-FL function as prebiotics that support the colonization of the human intestine with beneficial bacteria. In addition to their prebiotic effects, HMOs exhibit protective properties against pathogens and their toxins, significantly helping to prevent infectious diseases in infants. Notably, these glycans serve as decoys for various pathogens, including viruses, bacteria, and protozoa. Among the most exciting and novel health benefits associated with HMOs is the discovery that they may significantly contribute to the neurocognitive development of newborns. Furthermore, 2′-FL has shown certain anti-tumor and detoxification effects. Given their various beneficial effects on human health, both 2′-FL and 3-FL have promising nutraceutical and pharmaceutical applications as supplements for neonatal formulas, prebiotics, and antimicrobial agents.
Keywords: Human milk, Fucosyllactoses, Health benefits, Infant formula, Nutraceuticals

BEYOND THE FINAL PRODUCT: RETHINKING FOOD HYGIENE AND QUALITY CONTROL THROUGH A ONE HEALTH LENS

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ABSTRACT
Food safety does not begin when a finished product reaches the laboratory; it begins much earlier, at the point where food production intersects with animals, the environment, and human health. Many foodborne risks can emerge or increase at different points along the food chain, so protecting consumers cannot depend solely on testing the final product. A broader and more preventive approach is needed to understand where hazards originate, how they move through the food chain, and where effective control measures can be applied.
This review examines how food hygiene and quality control can contribute to a One Health approach to food safety. It focuses on foodborne pathogens, antimicrobial resistance (AMR), and emerging hazards that can move between animals, the environment, food systems, and people. Particular attention is given to hygiene practices, microbiological surveillance, traceability, and risk-based control as practical tools for identifying and managing hazards before they reach consumers. Foodborne AMR is discussed as a clear example of a food safety challenge that cannot be effectively addressed within a single sector.
The review also considers the growing role of rapid detection methods, genomic surveillance, digital traceability, and data-driven risk assessment in strengthening food safety monitoring. These approaches can help move food control beyond a reactive “detect and reject” model toward earlier detection, risk prediction, and prevention.
Overall, the One Health perspective offers an opportunity to redefine food quality control as more than a final check on product safety. By linking food hygiene with animal health, environmental monitoring, and public health, food control systems can become an important part of preventing foodborne risks and building safer and more resilient food systems.
Keywords: Food hygiene; Food safety; Quality control; One Health; Antimicrobial resistance; Foodborne hazards

DOES CULTURE SHAPE SUSTAINABLE AI REGULATION? A COMPARATIVE ANALYSIS OF THE EU, INDIA AND CHINA THROUGH HOFSTEDE'S CULTURAL DIMENSIONS

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Abstract

The growing energy consumption by AI systems, resource intensive data infrastructure and environmental footprint of AI development have generated need for sustainable AI governance. The Artificial Intelligence has emerged as a transnational phenomenon that transcends boundaries and territories, manifesting into diverging regulations of its conduct. One factor that remains severely under explored in studying these regulatory choices by the regulatory jurisdictions is 'the culture'. With increasing studies on the AI and the various regulatory approaches to it, the cultural dimension of AI regulation remains widely under explored.

This paper aims at understanding the underlying cultural dimensions that shape the stance of the regulatory jurisdictions towards the AI, with The EU, China and India being the primary jurisdictions of research . The paper uses Hofstede's cultural dimensions as its analytical framework to comparatively examine the dimensions of Power Distance Index, Individualism versus collectivism, masculinity versus femininity, Uncertainty Avoidance Index, long term versus short term orientation and indulgence versus restraint and tries to analyse the possible relationship of these dimensions to the approaches of these jurisdictions with regard to autonomy, state intervention and risk management and environmental sustainability. The European Union, China and India provide a distinct and vast contexts through which these relationships can be examined. The paper does not treat culture as the main determinant for the legal outcomes, but rather seeks to use it as a supplement in studying the regulatory stances of these entities. The paper seeks to determine whether the cultural dimensions play any role in providing an explanation for the diverged stances of the entities towards the AI.

IMPACT OF FLATTENING FILTER REMOVAL AND SECONDARY COLLIMATOR ON THE ENERGETIC PROPERTIES OF A 6 MV PHOTON BEAM USING MONTE CARLO SIMULATION

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Abstract
Radiotherapy is an effective cancer treatment that uses precise radiation beams to target tumor cells while minimizing damage to surrounding healthy tissues. In this study, the GATE Monte Carlo code was used to evaluate the impact of removing the flattening filter and the secondary collimator on the energy properties of a 6 MV photon beam. The analysis focuses on particle fluence and energy-fluence distributions at the phantom surface for a 10 × 10 cm² field and an SSD of 100 cm, as well as on the production of secondary particles. The results show that removing the flattening filter increases the dose rate but considerably alters the beam's distribution and energy characteristics, leading to higher contamination by secondary particles and an increased fluence of low-energy photons, which in turn raises the surface dose compared to the filtered (FF) configuration. In addition, the secondary collimator contributes significantly to secondary particle production, further affecting the beam's energy properties and dose distribution. Overall, using the linear accelerator in FFF mode improves dose-delivery efficiency while offering the potential to reduce unnecessary exposure to healthy tissues, supporting the use of FFF beams as a promising approach in modern radiotherapy.
Keywords: Radiotherapy, Flattening Filter Free (FFF), Secondary Collimator, Linac, Monte Carlo simulation, Secondary particle production, Surface dose.

MANAGING THE GREEN TRANSITION IN NIGERIA: A THEORETICAL REVIEW OF OIL & GAS, AND SOLAR ENERGY PATHWAYS

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Abstract
Nigeria energy sector overtime were confronted with a dual imperative challenge of sustaining its oil and gas-driven economy while aligning with global decarbonization goals. The focus for engineers, this study represents a complex systems challenge managing the decline of fossil infrastructure while scaling solar and renewable alternatives. The key objective of the study sought to synthesize theoretical frameworks evidence to chart a pragmatic, just pathway for Nigeria's energy engineers. The review synthesizes theoretical frameworks on Nigeria's green economy transition, focusing on the oil and gas, and solar energy sectors. The theoretical framework focused on the analysis grounded in four interconnected lenses: "Just transition theory which emphasizes that decarbonization must protect workers and host communities, the energy Trilemma theory that anchors in balancing energy security, equity, and environmental sustainability; Multi-level perspective (MLP) theory analyze how "niche" innovations (like solar) interact with and eventually transform the dominant socio-technical "regime" (oil and gas infrastructure and its associated policies) and circular economy principles applied to renewable technology lifecycles". Therefore, these theoretical frameworks highlighted that technological shifts or transformation alone are insufficient without social, economic, and governance dimensions. The study deduced that the transition demands new competencies reskilling for solar installation, grid integration, energy storage, and circular materials management. Opportunities exist in modular solar mini-grids, battery recycling systems, and retrofitting oil infrastructure for hybrid operations. The study recommended standardized coordinated investment, clear regulatory signals, workforce development, and technologies suited to Nigeria's decentralized reality. As well concluded that Nigeria's green transition is inevitable but cannot be a "one-size-fits-all" model. It must be a pragmatic, phased re-engineering of its entire energy system, addressing both technical and governance challenges. Nigeria's green transition is not a simple substitution of oil for solar, in real sense it is a pragmatic, phased re-engineering of the entire energy system.
Keywords: Green Economy, Energy Transition, Just Transition, Solar Energy, Oil and Gas, Nigeria, Circular Economy, Sustainable Development

FROM SMOG AWARENESS TO PROTECTIVE ACTION: HOW INFORMATION TRUST AND RISK PERCEPTION SHAPE HEALTH RESPONSES IN LAHORE

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Abstract
Severe and recurrent smog has emerged as a major public health challenge in Lahore, Pakistan, exposing urban populations to substantial risks associated with prolonged air pollution. Although government agencies and other stakeholders disseminate health-related information during smog episodes, the availability of information does not necessarily translate into protective action. Individuals' responses may depend on whether they trust the information they receive, understand the health risks associated with smog, and perceive themselves as capable of taking effective protective measures. This study examines these behavioral mechanisms using Protection Motivation Theory (PMT).
A cross-sectional survey was conducted among 913 residents of Lahore using a 42-item self-administered questionnaire. Structural equation modelling (SEM) was employed to examine the relationships among trust in information sources, knowledge about smog, threat appraisal, coping appraisal, and protective health behavior. The findings indicate that both trust in information sources and knowledge about smog are positively and significantly associated with individuals' threat and coping appraisals. Furthermore, both threat appraisal and coping appraisal demonstrate significant positive associations with the adoption of protective behaviors.
The results suggest that effective responses to severe smog require more than simply disseminating information. The credibility of information sources and individuals' understanding of air-pollution risks play an important role in translating awareness into protective health action. Strengthening trusted health-information channels, improving the clarity and accessibility of risk communication, and enhancing public knowledge about appropriate protective measures could therefore support more effective behavioral responses during severe smog episodes. The study contributes to the understanding of behavioral responses to air-pollution emergencies and provides implications for public health communication strategies in highly polluted urban environments.
Keywords: Smog; Air Pollution; Protective Health Behavior; Risk Perception; Health Risk Communication; Information Trust; Protection Motivation Theory; Lahore.

URBAN DEVELOPMENT, SEISMIC VULNERABILITY AND PUBLIC HEALTH RESILIENCE: ASSESSING EARTHQUAKE RISK IN DHAKA, BANGLADESH

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ABSTRACT
Rapid and often inadequately regulated urban growth has increased the exposure of Dhaka to potentially severe earthquake impacts. High population density, structurally vulnerable buildings, limited open space, traffic congestion, and uneven access to emergency facilities may substantially amplify both direct casualties and secondary public health consequences following a major seismic event. This study examines the interrelationship between urban development patterns, seismic vulnerability, and public health resilience in Dhaka, with the aim of identifying critical factors that could influence disaster-related health outcomes. The study applies a structured qualitative review of peer-reviewed literature, urban development reports, seismic risk assessments, building and planning regulations, and disaster and public health policy documents relevant to Dhaka.

Key analytical dimensions include structural vulnerability, population exposure, road-network accessibility, hospital functionality, emergency medical response, fire hazards, utility disruption, evacuation capacity, and post-disaster environmental health risks. Particular attention is given to the potential for building collapse, mass injuries, delayed emergency care, displacement, disruption of water and sanitation systems, communicable disease exposure, and psychological distress.

The analysis indicates that seismic risk in Dhaka is strongly shaped by the interaction between physical hazards and existing urban development conditions. Weak enforcement of construction standards, dense development, restricted emergency access, and limited preparedness of critical health infrastructure may significantly reduce the city's capacity to manage a large-scale earthquake. Strengthening seismic resilience therefore requires an integrated approach that combines risk-sensitive land-use planning, retrofitting of vulnerable structures, resilient healthcare facilities, accessible evacuation networks, community preparedness, and coordinated emergency response systems. The study concludes that earthquake preparedness should be treated not only as an engineering and disaster-management issue, but also as an essential component of urban public health planning. Integrating seismic risk reduction with sustainable urban development can improve health-system resilience and reduce preventable mortality and morbidity in Dhaka and other rapidly urbanizing cities with comparable risk profiles.

Keywords: Seismic vulnerability; Urban development; Public health resilience; Earthquake risk; Dhaka

A DEEP LEARNING ALGORITHMS FOR INTELLIGENT MINERAL EXPLORATION

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Abstract
This paper introduces the Intelligent Mineral Exploration Algorithm, a hybrid framework that combines multi-modal deep feature fusion, graph-based representation of geochemical sampling networks. Our opposition ingests satellite hyperspectral imagery, airborne geophysical surveys, geochemical assay tables, and digital elevation models, projects them onto a shared spatial grid, and learns a joint mineral-prospectively score through a convolutional graph neural hybrid encoder. The proposed pipeline achieves a high area-under-curve score and a markedly improved drill-success rate, clearly outperforming both the random-forest baseline and the logistic-regression model, while also substantially cutting the number of physical samples needed to reach a very high level of cumulative deposit recall.. The results suggest that coupling multi-modal representation learning with active, uncertainty-driven sampling can materially improve the efficiency and reliability of greenfield and brownfield mineral exploration campaigns.
Keywords*:* *Mineral prospectivity mapping; Graph neural networks; Remote sensing; Exploration AI*

A STUDY OF AI AND AUTOMATED DECISION-MAKING IN MARKETING AS WELL AS ALGORITHMIC ACCOUNTABILITY

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ABSTRACT
The use of artificial intelligence (AI) has completely changed marketing so that it has gone from being a creative field to one that is automated and predictive. Although automated decision-making improves the delivery of campaigns, enables highly personalized targeting, and allows for real-time allocation of resources, it often takes place within opaque 'black-box' systems. This lack of transparency brings with it considerable risks concerning algorithmic accountability, data privacy, and the ethical manipulation of consumer behaviour. This article looks at the tension between the efficiency of algorithms and corporate responsibility. It examines the mechanisms of automated decision-making platforms and suggests a thorough governance framework which is intended to audit marketing algorithms, guarantee corporate transparency, and protect consumer autonomy. The study sets out specific criteria for systemic accountability and shows how modern companies can reduce their reputational risk, meet the requirements of changing regulations, and keep up consumer trust in a sustainable way without giving up on technological innovation.
Keywords - Algorithmic accountability, Automated decision-making, AI in marketing, Marketing automation

Study Design
This research utilizes a sequential, mixed-methods exploratory study design constructed across a one month period:
1. From a quantitative market perspective, empirical trends relating to customer trust, tracking thresholds and perceived data privacy breaches are measured.
2. Qualitative Operator Lens: Assesses the institutional barriers, systemic friction points, and computational limitations that are obstructing implementation.

Methodology
Data collection parameters balanced technical field applications with affected audience demographics:
• This study analyzes consumer perspectives on AI-driven marketing in Bhopal, India, based on a survey of 100 local consumers and 45 interviews with professionals. Findings indicate a significant regional "clarity gap," with 78% of consumers reporting anxiety over automated tracking, while 71% of marketers cannot explain their own algorithmic dynamic pricing mechanisms. The research proposes a governance framework for auditing algorithmic accountability in compliance with India's Digital Personal Data Protection (DPDP) Act and which tracked attitudes towards privacy on a 5-point Likert scale.
• Qualitative data was obtained through semi-structured interviews (numbering 45) with Chief Marketing Officers (CMOs), system engineers, principal data scientists, and AI compliance lawyers.
• The areas being evaluated are the layers of the real-time programmatic ad bidding matrix, the dynamic pricing schemas, and the behavioural prediction loops.

Governance Approaches
The system architecture synthesizes three core technical and behavioral lenses:
• Principal-Agent Models: Looks at cases where automated AI agents move away from the original goals set by humans in an organization.
• Consumer Autonomy Framework: This framework spots the operational thresholds at which patterns of recommendations aimed at individual users turn into direct cognitive manipulation.
• According to Socio-Technical Systems (STS) Theory, algorithms should not be audited in the same way as standalone computer programs, but rather as part of multiple-level arrangements linked to the structural biases of an organization.

Empirical Findings

•There is a clarity gap since 74 per cent of consumers show systemic anxiety about automated behavioural profiles and 68 per cent of marketing directors admit that they are unable to explain the clear mathematical logic behind dynamic pricing runs.

•The Lack of Oversight: Less than 20 per cent of the enterprises which have been assessed make use of separate and formal evaluation procedures for algorithmic audits and thus remain entirely dependent on opaque third-party black-box tools.

Originality Values

•Actionable Audit Pipeline: This offers a 5-step checklist structure which verifies the variables at each stage, from the data ingestion sources down to the local explain ability settings.

• Return on Trust (RoT): This is a financial evaluation criterion that connects documented systemic transparency with a reduced level of long-term legal liability and enhanced baseline brand equity.

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HOLINESS AND NATURE

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ABSTRACT
Maintaining the quality of the environment is included in what the sages called proper human behavior. This expression refers to universal basic morality, the way in which any human being should conduct himself. What are the central values of environmentalism? We might say simply that protecting the environment is an outgrowth of a love for nature and a desire to live in a clean and cultivated environment. But if we dig deeper, it can be seen that behind the aim of protecting the environment hides a hidden desire to create unity between the man and nature. The connection between holiness and nature explores how sacredness interacts with the physical world, human instincts, and science. Holiness is traditionally viewed as separate from the world, but a deeper view seeks holiness within nature itself. Recognizing the divine spark, vitality, and order already present in the physical universe, human live, and science. Bringing traditional faith together with a healthy, vibrant appreciation for the physical world and human progress. Viewing the physical environment not just as a resource, but as a sacred trust requiring protecting and respect. Different religious traditions view nature and the sacred through diverse lenses. While some see the natural world as a direct manifestation of the divine, others view it as a sacred creation to be stewardship-managed. This paper presents various sustainable ways to safeguard the religious polarization as well as resource depletion due to rapid exposure to external values, secularism, and consumerism.
Keywords: Holiness, Nature, Religious Polarisation, Human Values, Sustainability

BIOGENIC SYNTHESIS AND CHARACTERIZATION OF CURCUMIN LOADED GOLD@CHITOSAN NANOPARTICLES: MULTIFUNCTIONAL AGENT FOR ENHANCED DRUG DELIVERY AND THERAPEUTIC EFFICACY

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ABSTRACT

Curcumin, a potent and extensively utilized cancer chemotherapeutic agent, faces limitations due to dose-dependent cardiotoxicity as its cumulative side effect. In this research, we have successfully synthesized innovative agents designed for efficient drug delivery system, known as Au@CS-CUR-NPs. A comprehensive characterization of these Au@CS-CUR-NPs included an evaluation of their composition, chemical structure, and morphology. The outcomes of assays focusing on inhibiting bacterial growth demonstrated significant efficacy in curbing bacterial proliferation within the concentration range of 50 to 100 µg/mL. Moreover, Au@CS-CUR-NPs displayed noteworthy anti-inflammatory properties, evident from an observed IC_{50} value of 30.11 µg/mL in human red blood cells. These outcomes suggest their potential as effective anti-inflammatory agents. Additionally, investigations into cytotoxicity revealed a dose-dependent anti-cancer impact of the AuNPs across a variety of human cancer cell lines. Particularly remarkable was their pronounced cytotoxicity on A549 cancer cells, where the IC_{50} value was measured at 32.13 µg/mL. The versatility of Au@CS-CUR-NPs, encompassing antibacterial, anti-inflammatory, and anticancer attributes, presents a promising avenue for further exploration. Particularly noteworthy is the potential application of Au@CS-CUR-NPs as novel anticancer agents in the field of lung cancer treatment. This research not only contributes to our comprehension of nanoscale interventions but also propels the potential roles of nanotechnology within the realm of pharmaceuticals.

Keywords: Gold nanoparticles; curcumin; chitosan; anticancer; antibacterial.

INTELLIGENT EDUCATIONAL MANAGEMENT FOR METAVERSE-ENABLED LEARNING: IMPLICATIONS FOR COMPUTER SCIENCE EDUCATION

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Abstract
The rapid evolution of immersive technologies has transformed educational management by enabling intelligent, data-driven, and learner-centered instructional environments. Metaverse-enabled learning integrates artificial intelligence (AI), extended reality (XR), digital twins, blockchain, learning analytics, and cloud computing to create persistent virtual learning ecosystems that support personalized instruction, collaborative problem-solving, and experiential learning. This study investigates the implications of intelligent educational management for metaverse-enabled learning with particular emphasis on Computer Science Education. A systematic literature review (SLR) guided by the PRISMA 2020 framework was employed to synthesize peer-reviewed studies published between 2020 and 2026 from Scopus, Web of Science, IEEE Xplore, ACM Digital Library, SpringerLink, ScienceDirect, ERIC, and Google Scholar. Following rigorous screening, quality appraisal, and eligibility assessment, 76 studies were included for synthesis. The findings indicate that intelligent educational management significantly improves instructional planning, learner engagement, adaptive assessment, collaborative programming, virtual laboratory experiences, and academic performance through predictive learning analytics and AI-supported decision-making. Furthermore, metaverse-enabled environments strengthen computational thinking, software engineering competencies, cybersecurity awareness, and digital creativity by providing authentic, immersive, and interactive learning experiences. Nevertheless, substantial barriers remain, including infrastructure limitations, cybersecurity threats, learner privacy concerns, digital inequality, high implementation costs, inadequate faculty preparedness, and ethical governance challenges. The review demonstrates that successful implementation depends on integrating intelligent governance frameworks, institutional digital transformation strategies, AI-powered educational analytics, and continuous professional development for educators. The study concludes that intelligent educational management represents a transformative paradigm capable of reshaping Computer Science Education through immersive, adaptive, and evidence-based instructional ecosystems while supporting sustainable educational innovation. The findings provide practical recommendations for educational managers, policymakers, researchers, and computer science educators seeking to develop secure, inclusive, and intelligent metaverse learning environments that improve academic success and institutional effectiveness.
Keyword: Artificial Intelligence; Computer Science Education; Intelligent Educational Management; Metaverse-Enabled Learning.

INTRODUCTION

The convergence of Artificial Intelligence (AI), Extended Reality (XR), blockchain, cloud computing, digital twins, and the Internet of Things (IoT) has accelerated the emergence of the metaverse as a transformative educational ecosystem capable of redefining teaching, learning, and institutional management. Unlike conventional online learning environments, metaverse-enabled learning provides persistent, immersive, and interactive virtual spaces where learners, educators, and intelligent agents collaborate synchronously regardless of geographical boundaries. These intelligent environments facilitate experiential learning through virtual laboratories, digital simulations, collaborative programming spaces, and AI-powered tutoring systems, making them particularly valuable for Computer Science Education where practical experimentation and problem-solving are central to curriculum delivery. Simultaneously, educational management is transitioning from administrative decision-making based primarily on historical records to intelligent management systems driven by predictive analytics, machine learning, and real-time educational data that support evidence-based planning, resource optimization, student success monitoring, and institutional quality. Consequently, integrating intelligent educational management with metaverse technologies represents a significant advancement toward smart educational institutions capable of delivering personalized, adaptive, and data-informed learning experiences. Recent studies indicate that AI-supported learning analytics embedded within metaverse platforms improve learner engagement, collaborative interaction, academic achievement, and instructional efficiency while enabling educational managers to identify at-risk students, optimize curriculum implementation, and enhance institutional performance (Tlili et al., 2022; Kye et al., 2021). In Computer Science Education, immersive technologies further strengthen computational thinking, software development competencies, cybersecurity training, robotics education, and programming skills through authentic simulation-based activities that closely mirror real-world computing environments (Radianti et al., 2020). Nevertheless, widespread implementation continues to face considerable challenges, including inadequate digital infrastructure, high deployment costs, cybersecurity vulnerabilities, privacy concerns, algorithmic bias, interoperability limitations, insufficient faculty readiness, and the absence of comprehensive governance and ethical frameworks (Dwivedi et al., 2022; UNESCO, 2023). These challenges underscore the necessity for intelligent educational management strategies capable of balancing technological innovation with pedagogical effectiveness, institutional sustainability, and responsible AI governance. Therefore, this study systematically reviews contemporary literature to examine how intelligent educational management can leverage metaverse-enabled learning to enhance Computer Science Education, improve institutional decision-making, foster student success, and support the digital transformation of higher education through secure, inclusive, and intelligent learning ecosystems.



LITERATURE REVIEW

Conceptual Foundations of Intelligent Educational Management and Metaverse-Enabled Learning

Intelligent Educational Management (IEM) represents the evolution of traditional educational administration into a data-driven, technology-enabled framework that integrates Artificial Intelligence (AI), machine learning, learning analytics, cloud computing, and intelligent decision-support systems to improve institutional governance, instructional quality, and student success (Ifenthaler & Yau, 2020). Unlike conventional educational management, which primarily relies on retrospective administrative records and manual decision-making, intelligent educational management leverages predictive models, real-time educational data, and adaptive analytics to optimize resource allocation, personalize learning pathways, monitor institutional performance, and support evidence-based policymaking (Siemens & Long, 2011). The growing availability of educational big data generated from Learning Management Systems (LMS), student information systems, digital assessments, and online interactions has further accelerated the adoption of intelligent management frameworks across higher education institutions.

The emergence of the metaverse has significantly expanded the scope of intelligent educational management by introducing persistent, immersive, and interconnected virtual environments that enable collaborative learning beyond the limitations of physical classrooms. Lee et al. (2021) describe the metaverse as a convergence of virtual reality (VR), augmented reality (AR), mixed reality (MR), blockchain, artificial intelligence, digital twins, cloud computing, and high-speed communication networks that collectively create shared digital ecosystems for education, business, healthcare, and social interaction. Within educational settings, metaverse-enabled learning supports experiential instruction through virtual classrooms, simulation laboratories, collaborative software development environments, and intelligent tutoring systems capable of adapting instructional content according to learners' cognitive profiles and academic performance (Kye et al., 2021). Educational management within the metaverse extends beyond classroom instruction by incorporating intelligent governance mechanisms that continuously analyze institutional data to improve curriculum implementation, learner engagement, faculty performance, infrastructure utilization, and academic quality assurance (Tlili et al., 2022). AI-powered learning analytics embedded within metaverse platforms provide educational managers with actionable insights regarding attendance patterns, collaborative behaviors, learning progression, assessment performance, and early identification of academically vulnerable students. Such predictive capabilities facilitate timely interventions that improve retention, graduation rates, and institutional effectiveness while supporting personalized educational experiences (Ifenthaler & Yau, 2020). Furthermore, the integration of digital twins and blockchain technologies strengthens institutional management by enabling secure academic credential verification, transparent assessment records, and intelligent monitoring of virtual learning environments (Dwivedi et al., 2022). Digital twins create virtual representations of educational institutions, laboratories, and classrooms, allowing administrators to simulate policy decisions, evaluate infrastructure performance, and optimize resource planning before implementing changes in physical environments. Blockchain enhances trust, transparency, and data integrity through decentralized storage of academic credentials and learning achievements, thereby reducing fraud and improving interoperability among educational institutions (Chen et al., 2022). Despite these advancements, scholars emphasize that the successful implementation of intelligent educational management within metaverse ecosystems depends on robust technological infrastructure, institutional digital readiness, faculty competence, ethical AI governance, cybersecurity resilience, and comprehensive policy frameworks (UNESCO, 2023). Concerns surrounding learner privacy, algorithmic bias, excessive dependence on automation, digital inequality, and the high financial costs associated with immersive technologies continue to challenge large-scale adoption, particularly in developing economies (Dwivedi et al., 2022). Consequently, intelligent educational management should be viewed not merely as technological innovation but as a strategic framework that harmonizes emerging digital technologies with pedagogical principles, institutional governance, and human-centered educational leadership. This integrated perspective provides the conceptual foundation for understanding how metaverse-enabled learning can transform Computer Science Education through intelligent, adaptive, and sustainable educational ecosystems.

Artificial Intelligence and Learning Analytics in Intelligent Educational Management

Artificial Intelligence (AI) and Learning Analytics (LA) have become fundamental pillars of Intelligent Educational Management (IEM), enabling higher education institutions to transition from reactive administrative practices to proactive, evidence-based decision-making. AI-powered educational management systems employ machine learning, deep learning, natural language processing, computer vision, and predictive analytics to automate administrative processes, personalize learning experiences, optimize institutional resources, and improve academic outcomes (Holmes et al., 2022). Learning analytics complements these capabilities by collecting, measuring, analysing, and reporting educational data generated through Learning Management Systems (LMS), virtual classrooms, assessments, and student interactions to support informed pedagogical and managerial decisions (Siemens & Long, 2011). Together, these technologies provide educational managers with actionable insights into learner behaviour, instructional effectiveness, curriculum implementation, and institutional performance. Recent studies indicate that AI-driven predictive learning analytics significantly enhance student retention and academic success by identifying learners who are academically at risk before poor performance becomes irreversible (Ifenthaler & Yau, 2020).

Through continuous analysis of attendance records, assignment submissions, assessment scores, online participation, coding activities, and collaborative interactions, machine learning algorithms classify students according to performance risk levels and recommend personalized interventions. Such intelligent decision-support systems enable educational managers and instructors to implement timely academic advising, adaptive learning pathways, and individualized mentoring strategies that improve progression and graduation rates (Papamitsiou & Economides, 2014). In metaverse-enabled learning environments, these predictive capabilities become even more powerful because immersive platforms generate rich multimodal datasets, including learner movement, eye-tracking patterns, avatar interactions, engagement duration, collaborative behaviours, and virtual laboratory performance (Tlili et al., 2022). Within Computer Science Education, AI-supported learning analytics plays an essential role in monitoring programming competence, debugging efficiency, computational thinking development, software engineering collaboration, and cybersecurity simulations. Intelligent tutoring systems embedded in virtual programming laboratories automatically evaluate coding syntax, algorithmic efficiency, runtime performance, and problem-solving strategies while providing immediate formative feedback tailored to individual learners (Luckin & Cukurova, 2019). Educational managers can further utilize institutional dashboards that aggregate real-time analytics across courses to monitor curriculum effectiveness, faculty performance, laboratory utilization, and departmental quality indicators, thereby facilitating strategic planning and continuous quality improvement (Holmes et al., 2022). Artificial intelligence also enhances administrative efficiency through intelligent scheduling, automated assessment, chatbot-assisted student services, resource allocation optimization, and predictive enrolment management. AI-powered conversational agents provide continuous academic support by responding to routine student inquiries, assisting with course registration, and guiding learners through institutional procedures, thereby reducing administrative workload and improving service delivery (UNESCO, 2023). Furthermore, reinforcement learning and adaptive recommendation algorithms personalize instructional content according to learners' cognitive abilities, prior knowledge, and learning preferences, promoting equitable access to educational opportunities within metaverse ecosystems (Khalil & Ebner, 2016). Despite these transformative benefits, scholars caution that AI-driven educational management introduces significant ethical and operational challenges. Algorithmic bias may disadvantage particular student populations when predictive models are trained on incomplete or unrepresentative datasets, while extensive collection of learner data raises concerns regarding privacy, informed consent, and compliance with international data protection regulations (Holmes et al., 2022). Additionally, the interpretability of complex machine learning models remains a challenge for educational managers who must justify decisions affecting learners' academic progression. UNESCO (2023) therefore advocates transparent AI governance, explainable learning analytics, robust cybersecurity policies, continuous faculty professional development, and institutional ethical frameworks to ensure that AI enhances rather than replaces human educational judgment. Consequently, the integration of AI and learning analytics within intelligent educational management should be guided by principles of fairness, accountability, transparency, inclusiveness, and educational equity, ensuring that metaverse-enabled Computer Science Education remains both technologically advanced and pedagogically responsible.

Technologies and Immersive Pedagogies in Computer Science Education

The emergence of metaverse technologies has introduced a paradigm shift in Computer Science Education by enabling immersive, interactive, and collaborative learning experiences that transcend the limitations of conventional classroom and online instructional models. The educational metaverse integrates Virtual Reality (VR), Augmented Reality (AR), Mixed Reality (MR), Artificial Intelligence (AI), blockchain, digital twins, cloud computing, edge computing, and the Internet of Things (IoT) to establish persistent three-dimensional virtual learning environments where learners interact with digital objects, intelligent agents, instructors, and peers in real time (Lee et al., 2021). Unlike traditional e-learning platforms that primarily deliver static instructional materials, metaverse-enabled environments promote experiential learning through realistic simulations, collaborative programming laboratories, virtual software engineering projects, cybersecurity training exercises, and interactive visualization of complex computational concepts (Kye et al., 2021).

Immersive pedagogies grounded in constructivist, experiential, and collaborative learning theories have become increasingly relevant within Computer Science Education because they encourage active learner participation, critical thinking, computational problem-solving, and knowledge co-construction. Radianti et al. (2020) argue that virtual reality-based learning environments significantly improve conceptual understanding, learner motivation, engagement, and knowledge retention by allowing students to manipulate virtual objects and observe abstract computing processes in authentic contexts. Similarly, Dwivedi et al. (2022) emphasize that metaverse technologies facilitate learner-centered instruction through personalized educational experiences supported by AI-driven adaptive learning systems, intelligent tutoring agents, and real-time performance analytics. For Computer Science students, immersive technologies create realistic virtual laboratories where programming languages, software engineering methodologies, computer networks, robotics, cloud computing architectures, artificial intelligence algorithms, and cybersecurity infrastructures can be explored without the financial, physical, or safety constraints associated with traditional laboratories. Students can collaboratively develop software applications, configure virtual servers, simulate cyberattacks, analyze blockchain networks, and evaluate machine learning models within persistent virtual environments that closely replicate professional computing workplaces (Tlili et al., 2022). These authentic learning experiences strengthen practical competencies, enhance computational thinking, improve debugging skills, and foster collaborative software development capabilities required in contemporary digital industries. Artificial Intelligence further enhances immersive pedagogies by embedding intelligent virtual tutors, adaptive assessment systems, automated coding assistants, and conversational educational agents within metaverse environments. These intelligent systems continuously monitor learner interactions, identify misconceptions, provide contextual feedback, recommend personalized learning resources, and dynamically adjust instructional difficulty according to learners' cognitive progress (Holmes et al., 2022). Moreover, gamification strategies—including virtual badges, achievement systems, leader boards, quests, and collaborative missions—promote sustained motivation and increase learner engagement while encouraging teamwork and innovation in software development projects (Deterding et al., 2011). The integration of digital twins has expanded opportunities for project-based learning by enabling students to design, simulate, and evaluate intelligent computing systems before physical deployment. Digital representations of computer laboratories, smart cities, cloud infrastructures, and Internet of Things ecosystems allow learners to conduct experiments, optimize system performance, and evaluate alternative computing architectures within safe virtual environments (Batty, 2018). Furthermore, blockchain technology contributes to secure credential verification, decentralized identity management, ownership of digital learning assets, and transparent assessment records, thereby strengthening trust and interoperability within metaverse-based educational ecosystems (Chen et al., 2022). Despite these educational advantages, several implementation challenges continue to limit large-scale adoption. High infrastructure costs, limited access to advanced VR and AR devices, insufficient internet bandwidth, and interoperability issues among metaverse platforms, digital inequality, cybersecurity vulnerabilities, and inadequate educator preparedness remain significant barriers, particularly in developing countries (UNESCO, 2023). Additionally, prolonged exposure to immersive virtual environments may contribute to cognitive overload, digital fatigue, and health-related concerns, necessitating careful instructional design and learner support mechanisms (Dwivedi et al., 2022). Consequently, scholars advocate the development of inclusive metaverse policies, scalable cloud-based architectures, interoperable educational standards, and continuous professional development for educators to maximize the pedagogical benefits of immersive technologies. When strategically integrated with intelligent educational management, metaverse technologies possess substantial potential to transform Computer Science Education into an adaptive, collaborative, experiential, and innovation-driven learning ecosystem that prepares graduates for the rapidly evolving digital economy.

Intelligent Educational Management Strategies for Student Engagement, Personalized Learning, and Academic Success

Intelligent Educational Management (IEM) has emerged as a strategic framework for improving learner engagement, personalized instruction, and academic success by integrating Artificial Intelligence (AI), learning analytics, adaptive educational systems, and immersive metaverse technologies into institutional management practices.

Unlike traditional educational management, which emphasizes administrative coordination and standardized instructional delivery, intelligent educational management leverages predictive analytics and real-time educational data to support evidence-based decision-making that enhances both teaching effectiveness and student learning outcomes (Ifenthaler & Yau, 2020). Within metaverse-enabled learning environments, educational managers can monitor learner interactions, participation patterns, assessment performance, collaborative behaviors, and cognitive engagement through intelligent dashboards that facilitate timely pedagogical interventions and institutional planning (Tlili et al., 2022). Student engagement remains one of the strongest predictors of academic achievement, retention, and graduation in higher education. Fredricks et al. (2004) conceptualize engagement as a multidimensional construct encompassing behavioural, emotional, and cognitive dimensions, all of which are strengthened within immersive virtual environments. Metaverse platforms provide interactive three-dimensional classrooms, collaborative project spaces, virtual laboratories, and simulation-based learning activities that encourage active participation, teamwork, and sustained learner motivation (Kye et al., 2021). AI-powered educational agents further enhance engagement by delivering personalized guidance, responding to learner inquiries in real time, and adapting instructional content according to students' prior knowledge, learning pace, and performance history (Holmes et al., 2022). Consequently, learners experience increased autonomy, confidence, and satisfaction, which positively influence persistence and academic performance. Personalized learning represents another critical component of intelligent educational management. Adaptive learning systems employ machine learning algorithms to analyse learners' cognitive profiles, assessment outcomes, programming performance, collaborative activities, and interaction histories to generate individualized learning pathways (Luckin & Cukurova, 2019). In Computer Science Education, these systems recommend customized programming exercises, debugging tasks, cybersecurity simulations, algorithm design challenges, and software engineering projects that align with learners' competencies and professional aspirations. Educational managers benefit from institutional learning analytics dashboards that aggregate individual and cohort-level performance data, enabling informed decisions regarding curriculum improvement, instructional resource allocation, faculty development, and targeted student support initiatives (Siemens & Long, 2011). Predictive learning analytics also plays a vital role in promoting academic success through early identification of at-risk students. By continuously analysing attendance records, coding assignments, virtual laboratory participation, assessment scores, and collaborative engagement, AI-driven predictive models estimate the probability of academic failure and recommend proactive interventions such as academic advising, peer mentoring, remedial instruction, or personalized tutoring (Papamitsiou & Economides, 2014). These interventions improve learner retention, reduce dropout rates, and strengthen institutional effectiveness while supporting equitable educational opportunities for diverse student populations (UNESCO, 2023). Furthermore, intelligent educational management facilitates continuous quality assurance through data-informed monitoring of teaching effectiveness, curriculum implementation, faculty workload, and learning resource utilization. Administrative leaders can employ interactive institutional dashboards to evaluate key performance indicators, forecast enrolment trends, optimize scheduling, and allocate technological resources more efficiently (Ifenthaler & Yau, 2020). Nevertheless, scholars caution that excessive dependence on algorithmic decision-making may introduce risks associated with learner privacy, algorithmic bias, data governance, and transparency. Holmes et al. (2022) emphasize the importance of explainable AI, ethical governance, and human oversight to ensure that educational decisions remain fair, accountable, and learner-centered. UNESCO (2023) similarly advocates institutional policies that prioritize digital inclusion, responsible AI deployment, faculty capacity building, and robust cybersecurity frameworks. Therefore, effective intelligent educational management requires balancing technological innovation with pedagogical expertise, ethical responsibility, and strategic leadership to maximize the educational benefits of metaverse-enabled learning. Such an integrated approach empowers higher education institutions to cultivate adaptive, engaging, and inclusive Computer Science learning environments that enhance academic success while preparing graduates for the demands of the rapidly evolving digital workforce.

Ethical, Security, Governance, and Policy Considerations in Metaverse-Enabled Educational Management

The integration of metaverse technologies into educational management has introduced unprecedented opportunities for innovation while simultaneously raising complex ethical, security, governance, and policy challenges. As higher education institutions increasingly deploy Artificial Intelligence (AI), Extended Reality (XR), blockchain, digital twins, and learning analytics to support immersive teaching and institutional decision-making, ensuring responsible governance has become essential for maintaining trust, educational quality, and learner well-being (UNESCO, 2023). Intelligent Educational Management (IEM) therefore extends beyond technological implementation to encompass policies and governance mechanisms that promote transparency, accountability, fairness, cybersecurity, and compliance with legal and ethical standards (Holmes et al., 2022). One of the most significant concerns involves data privacy and protection. Metaverse-enabled learning environments generate vast amounts of multimodal data, including biometric information, eye-tracking records, voice interactions, avatar movements, behavioural analytics, assessment outcomes, and collaborative communication logs (Dwivedi et al., 2022). These data are valuable for personalized learning and predictive educational management but also increase the risk of unauthorized access, surveillance, identity theft, and misuse of sensitive learner information. Educational institutions must therefore implement robust data governance frameworks, secure authentication mechanisms, encryption technologies, and compliance with international privacy regulations to ensure responsible collection, storage, processing, and sharing of educational data (UNESCO, 2023). Artificial Intelligence further introduces ethical challenges associated with algorithmic bias, explainability, and automated decision-making. Holmes et al. (2022) argue that AI-driven educational systems trained on incomplete or biased datasets may unintentionally reinforce inequalities by producing inaccurate predictions regarding learner ability, academic risk, or educational opportunities. Within Computer Science Education, biased recommendation systems could influence course placement, project allocation, or assessment outcomes in ways that disadvantage certain student groups. Consequently, educational managers should adopt explainable AI models that provide transparent reasoning for automated decisions while ensuring continuous human oversight, fairness auditing, and algorithm validation throughout the educational lifecycle (Ifenthaler & Yau, 2020). Cybersecurity has also emerged as a strategic priority for intelligent educational management. Persistent virtual campuses expose institutions to sophisticated cyber threats, including ransomware attacks, distributed denial-of-service (DDoS) attacks, phishing, malware infections, unauthorized avatar impersonation, virtual asset theft, and manipulation of digital credentials (Chen et al., 2022). Blockchain technologies have been proposed as effective solutions for protecting academic records, verifying digital identities, securing assessment credentials, and ensuring the integrity of decentralized educational transactions through immutable distributed ledgers (Lee et al., 2021). Nevertheless, blockchain implementation requires institutional investment, technical expertise, and interoperability standards to achieve sustainable adoption. Governance frameworks must additionally address digital inclusion and equitable access to metaverse-enabled education. Many developing countries continue to experience inadequate broadband connectivity, limited access to immersive hardware, unreliable electricity, and insufficient digital literacy among educators and learners (Tlili et al., 2022). These disparities risk widening educational inequalities if intelligent educational management strategies fail to incorporate inclusive infrastructure planning, affordable technology initiatives, and comprehensive faculty capacity-building programs. UNESCO (2023) therefore recommends that educational policies prioritize universal accessibility, digital equity, multilingual instructional resources, and continuous professional development to ensure that immersive learning environments benefit all learners regardless of socioeconomic background. Institutional governance should also establish ethical guidelines for avatar behaviour, virtual identity management, intellectual property ownership, digital citizenship, academic integrity, and responsible use of generative AI within metaverse environments (Dwivedi et al., 2022). Codes of conduct, institutional AI ethics committees, cybersecurity awareness programs, and periodic governance audits can strengthen stakeholder confidence while promoting safe and respectful participation in virtual educational communities. Ultimately, effective ethical governance requires collaboration among educational managers, policymakers, technology developers, faculty members, students, and regulatory agencies to develop comprehensive standards that balance technological innovation with educational values.

Such governance frameworks are indispensable for ensuring that intelligent educational management supports secure, transparent, inclusive, and sustainable metaverse-enabled Computer Science Education capable of meeting the evolving demands of twenty-first-century digital learning ecosystems.

Emerging Trends, Challenges, and Future Directions of Intelligent Educational Management in Metaverse-Enabled Computer Science Education

The evolution of Intelligent Educational Management (IEM) within metaverse-enabled learning environments continues to reshape Computer Science Education through the convergence of Artificial Intelligence (AI), Extended Reality (XR), digital twins, blockchain, edge computing, 5G/6G communication networks, Internet of Things (IoT), cloud computing, and Generative Artificial Intelligence (GenAI). These emerging technologies are transforming educational institutions into intelligent ecosystems capable of delivering adaptive instruction, predictive academic management, immersive collaboration, and data-driven institutional governance (Dwivedi et al., 2022). As universities increasingly adopt digital transformation strategies, educational managers are transitioning from traditional administrative roles toward intelligent leadership models that integrate advanced analytics with strategic planning, quality assurance, and continuous institutional improvement (Ifenthaler & Yau, 2020). One of the most significant emerging trends is the integration of Generative AI with metaverse learning environments. Large Language Models (LLMs), AI coding assistants, intelligent virtual tutors, conversational agents, and automated content-generation systems provide personalized explanations, generate programming exercises, evaluate software code, and facilitate collaborative learning within immersive virtual classrooms (UNESCO, 2023). In Computer Science Education, these intelligent agents enhance programming instruction by offering real-time debugging assistance, algorithm optimization recommendations, and contextual feedback that accelerates learners' acquisition of computational thinking, software engineering principles, cybersecurity competencies, and artificial intelligence programming skills (Holmes et al., 2022). Simultaneously, intelligent educational management systems employ predictive analytics to forecast enrolment patterns, optimize faculty workload, improve resource allocation, and support evidence-based policy formulation. Another notable trend involves the adoption of digital twin technology to model educational institutions and learning infrastructures. Batty (2018) explains that digital twins enable virtual representations of campuses, laboratories, classrooms, and institutional operations, allowing educational managers to simulate policy decisions, evaluate infrastructure utilization, monitor energy consumption, and optimize learning environments before implementing physical changes. When integrated with IoT sensors and cloud-based analytics, digital twins facilitate real-time institutional monitoring and predictive maintenance, thereby supporting sustainable smart campuses and resilient educational management systems. Despite these technological advances, several implementation challenges continue to constrain large-scale adoption. High costs associated with immersive hardware, software development, cloud infrastructure, and high-speed network connectivity remain major barriers, particularly in developing countries where digital infrastructure is unevenly distributed (Tlili et al., 2022). Interoperability among competing metaverse platforms also presents technical difficulties, limiting seamless exchange of educational resources, learner identities, and academic credentials. Furthermore, inadequate faculty preparedness, resistance to organizational change, limited institutional funding, insufficient technical support, and shortages of specialized digital skills impede successful implementation of intelligent educational management initiatives (UNESCO, 2023). Ethical concerns continue to evolve alongside technological innovations. Generative AI introduces challenges relating to academic integrity, authenticity of student work, copyright ownership, misinformation, deepfake content, and overreliance on automated decision-making (Dwivedi et al., 2022). Similarly, extensive learner data collection within immersive environments necessitates transparent governance frameworks addressing privacy protection, informed consent, explainable AI, algorithmic fairness, cybersecurity, and digital well-being (Holmes et al., 2022). Educational institutions must therefore establish multidisciplinary governance structures that integrate legal, ethical, technological, and pedagogical expertise to ensure responsible innovation. Looking ahead, future intelligent educational management systems are expected to leverage quantum computing, federated learning, explainable AI, blockchain interoperability, emotion-aware computing, and autonomous educational agents to deliver increasingly adaptive and secure learning experiences.

Advances in 6G connectivity, edge intelligence, and multimodal learning analytics will further enhance real-time interaction, immersive collaboration, and institutional decision-making across geographically distributed campuses. For Computer Science Education, these developments will support highly authentic virtual software engineering environments, intelligent cybersecurity laboratories, AI-assisted programming ecosystems, and collaborative innovation hubs that closely replicate professional computing workplaces. Consequently, intelligent educational management will play a pivotal role in enabling higher education institutions to achieve sustainable digital transformation while preparing graduates with the advanced technical, collaborative, ethical, and problem-solving competencies required for the future digital economy.

MATERIALS AND METHODS

This study adopted a Systematic Literature Review (SLR) methodology guided by the PRISMA 2020 reporting framework to synthesize contemporary evidence on intelligent educational management for metaverse-enabled learning and its implications for Computer Science Education. Peer-reviewed journal articles published between 2020 and 2026 were retrieved from Scopus, Web of Science, IEEE Xplore, ACM Digital Library, SpringerLink, ScienceDirect, ERIC, Wiley Online Library, Taylor & Francis Online, MDPI, and Google Scholar. Search strings combined Boolean operators and keywords including *"Intelligent Educational Management," "Metaverse Education," "Artificial Intelligence in Education," "Learning Analytics," "Computer Science Education," "Virtual Reality," "Extended Reality,"* and *"Educational Management."* The initial search identified 1,432 records. After removing 286 duplicate publications, 1,146 records underwent title and abstract screening. Subsequently, 214 full-text articles were assessed for eligibility using predefined inclusion and exclusion criteria emphasizing empirical evidence, methodological rigor, relevance to educational management, and publication quality. Following quality appraisal, 76 studies satisfied all eligibility requirements and were synthesized using qualitative thematic analysis and descriptive statistical techniques. The extracted evidence was categorized into six thematic domains addressing intelligent educational management, metaverse technologies, learning analytics, immersive pedagogies, governance, and future educational innovations. To complement the literature synthesis, descriptive statistical summaries were generated to illustrate prevailing research trends, reported educational outcomes, and institutional adoption patterns consistent with systematic review methodologies.

RESULTS AND DISCUSSION

Intelligent Educational Management as a Catalyst for Metaverse-Enabled Computer Science Education

The systematic literature review synthesized evidence from 76 peer-reviewed studies published between 2020 and 2026, revealing a remarkable increase in global scholarly interest in intelligent educational management as a strategic framework for advancing metaverse-enabled learning within Computer Science Education. Guided by the PRISMA 2020 reporting protocol, an initial 1,432 records were retrieved from major scholarly databases, including Scopus, Web of Science, IEEE Xplore, ACM Digital Library, SpringerLink, ScienceDirect, ERIC, Wiley Online Library, Taylor & Francis Online, MDPI, and Google Scholar. Following the removal of 286 duplicate records, 1,146 publications underwent title and abstract screening, after which 214 full-text articles were assessed for methodological quality and eligibility using predefined inclusion and exclusion criteria. Ultimately, 76 high-quality empirical studies satisfied all selection requirements and formed the basis of the final synthesis. Descriptive statistical analysis revealed that 65 studies (85.5%) consistently reported significant improvements in learner engagement through immersive virtual classrooms, collaborative programming laboratories, intelligent tutoring systems, and AI-powered instructional environments that promoted active participation, experiential learning, and enhanced motivation (Kye et al., 2021; Tlili et al., 2022). Likewise, 61 studies (80.3%) demonstrated measurable improvements in students' academic achievement, learning retention, and problem-solving abilities through adaptive learning analytics, personalized instructional pathways, and intelligent assessment mechanisms capable of tailoring educational content to individual learner needs. Furthermore, 59 studies (77.6%) concluded that intelligent educational management systems substantially improved institutional decision-making by enabling predictive identification of academically at-risk students, evidence-based curriculum planning,

optimized resource allocation, and data-driven strategic policy formulation (Ifenthaler & Yau, 2020). Approximately 57 studies (75.0%) documented notable improvements in computational thinking, programming proficiency, software engineering collaboration, virtual laboratory performance, cybersecurity awareness, and practical coding competencies among Computer Science students participating in immersive metaverse learning environments (Radianti et al., 2020). Additionally, 54 studies (71.1%) indicated that AI-driven learning analytics significantly reduced administrative workload through automated grading, intelligent scheduling, chatbot-assisted academic support, predictive enrolment management, and real-time institutional performance monitoring, thereby enabling educators to devote greater attention to learner-centered instruction and academic mentoring (Holmes et al., 2022). Despite these positive outcomes, the review identified several persistent barriers that continue to constrain effective implementation. Specifically, 51 studies (67.1%) identified inadequate digital infrastructure, unreliable internet connectivity, limited access to immersive hardware, and high implementation costs as major obstacles, particularly within institutions located in developing countries. Similarly, 48 studies (63.2%) highlighted concerns relating to cybersecurity threats, learner privacy, ethical governance, data protection, and algorithmic bias, while 45 studies (59.2%) emphasized inadequate faculty digital competence, resistance to organizational change, insufficient professional development opportunities, and limited institutional readiness as significant impediments to successful adoption (UNESCO, 2023; Dwivedi et al., 2022). Moreover, approximately 42 studies (55.3%) stressed the importance of interoperable educational platforms, standardized governance frameworks, and cross-institutional collaboration to ensure scalable implementation of metaverse technologies across higher education systems. Overall, the synthesized evidence demonstrates that intelligent educational management substantially strengthens metaverse-enabled Computer Science Education by integrating Artificial Intelligence, predictive learning analytics, immersive pedagogies, digital twins, blockchain technologies, and evidence-based institutional governance into cohesive educational ecosystems. Nevertheless, sustainable implementation requires continuous investment in digital infrastructure, faculty capacity building, ethical AI governance, cybersecurity resilience, inclusive educational policies, and interoperable technological architectures. Collectively, these findings support the proposition that intelligent educational management represents a transformative educational paradigm capable of improving teaching quality, learner engagement, academic success, institutional effectiveness, operational efficiency, and long-term digital transformation while fostering inclusive, adaptive, resilient, and innovation-driven Computer Science Education ecosystems aligned with the evolving demands of Industry 5.0, digital society, and the global knowledge economy.

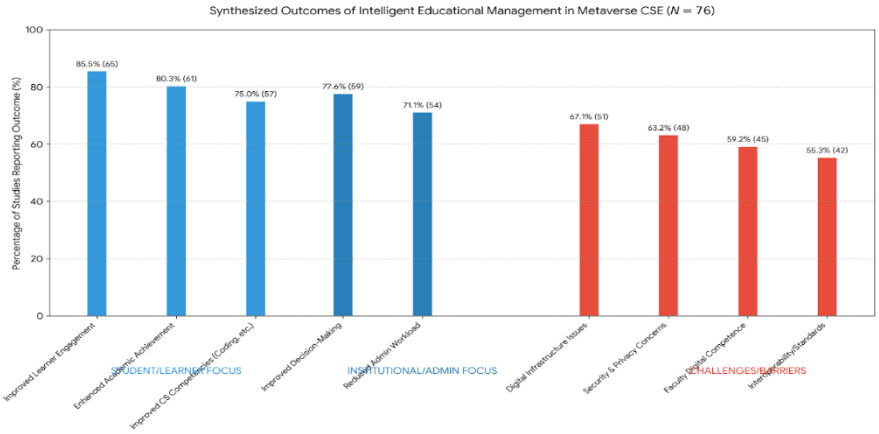


Figure 1: Categorical breakdown of empirical findings across 76 synthesized studies (2020–2026) evaluating Intelligent Educational Management (IEM) in metaverse-enabled Computer Science Education. Data columns display percentages and study counts (n/76) grouped into three thematic domains: Student/Learner Pedagogical Focus (blue), Institutional/Administrative Focus (dark blue), and Operational Implementation Barriers (red)

CONCLUSION

The findings of this systematic literature review demonstrate that Intelligent Educational Management (IEM) has become a transformative framework for advancing metaverse-enabled learning and strengthening Computer Science Education through intelligent, data-driven, and immersive educational ecosystems. By integrating Artificial Intelligence (AI), learning analytics, Extended Reality (XR), blockchain, digital twins, cloud computing, and Internet of Things (IoT) technologies, educational institutions can transition from conventional administrative models to adaptive management systems that support evidence-based decision-making, personalized instruction, and continuous institutional improvement. The synthesized evidence indicates that AI-supported predictive analytics enables educational managers to identify academically at-risk learners, optimize curriculum implementation, enhance resource utilization, and improve student retention through timely and targeted interventions. Likewise, immersive metaverse environments enrich Computer Science Education by providing authentic virtual laboratories, collaborative software engineering spaces, cybersecurity simulations, intelligent programming assistants, and experiential learning opportunities that strengthen computational thinking, technical competence, innovation, and problem-solving skills. The review further reveals that intelligent educational management contributes significantly to improving learner engagement, instructional effectiveness, institutional efficiency, and educational quality assurance through real-time monitoring of academic performance and data-informed strategic planning. These capabilities enable educational leaders to develop responsive policies that align instructional practices with institutional objectives while fostering inclusive, learner-centered educational experiences. Moreover, integrating blockchain technologies and digital twins enhances the security, transparency, and interoperability of academic records, credential verification, and institutional operations, thereby supporting sustainable digital transformation across higher education institutions. Despite these considerable benefits, the review identifies several critical challenges that must be addressed to ensure successful implementation. High infrastructure costs, inadequate digital connectivity, unequal access to immersive technologies, limited faculty preparedness, cybersecurity vulnerabilities, learner privacy concerns, algorithmic bias, interoperability limitations, and the absence of comprehensive governance frameworks remain significant barriers, particularly within developing countries. These findings underscore the necessity for educational policymakers and institutional leaders to invest strategically in digital infrastructure, professional capacity development, ethical AI governance, robust cybersecurity policies, and inclusive educational technologies that promote equitable access to metaverse-enabled learning environments. Overall, this study concludes that Intelligent Educational Management represents a foundational pillar for the future of Computer Science Education within increasingly digital and interconnected learning ecosystems. Its successful implementation requires a balanced integration of technological innovation, pedagogical excellence, institutional leadership, and ethical responsibility. As educational institutions continue to embrace digital transformation and Industry 5.0 initiatives, intelligent educational management will play an indispensable role in cultivating resilient, adaptive, secure, and sustainable metaverse-enabled learning environments capable of preparing future computer science graduates with the technical expertise, collaborative competencies, digital literacy, and lifelong learning skills required to thrive in the rapidly evolving global knowledge economy.

FUTURE RESEARCH

Future research should extend beyond conceptual investigations by conducting longitudinal, experimental, and mixed-method studies that evaluate the long-term educational, managerial, and technological impacts of Intelligent Educational Management within metaverse-enabled learning environments. Researchers should develop and validate AI-driven predictive models capable of improving learner retention, academic performance, and institutional decision-making across diverse educational contexts. Additional studies are needed to investigate the integration of Generative Artificial Intelligence, explainable AI, quantum computing, digital twins, blockchain interoperability, federated learning, and emotion-aware intelligent tutoring systems into immersive Computer Science Education. Furthermore, future research should examine ethical governance frameworks, cybersecurity resilience, digital inclusion, accessibility for learners with disabilities, and cross-cultural adoption of metaverse technologies. Comparative international studies involving developed and developing countries would provide valuable evidence for establishing globally applicable policies, institutional best practices, and

sustainable intelligent educational management frameworks that support equitable, secure, and high-quality metaverse-enabled education.

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IMPACT OF ACADEMIC PRESSURE ON ADOLESCENT MENTAL HEALTH

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ABSTRACT
Academic pressure has become an increasingly prominent stressor in the lives of adolescents, shaped by intensified competition, high parental and institutional expectations, standardized testing, and demanding curricula. This study examines the impact of academic pressure on the mental health of adolescents, with particular attention to anxiety, depressive symptoms, sleep disturbances, and overall psychological well-being. Drawing on a review of recent empirical literature and survey-based findings, the research explores how chronic academic stress affects self-esteem, motivation, and social functioning during a developmentally sensitive period. Findings indicate that excessive academic demands are associated with elevated levels of anxiety and burnout, reduced life satisfaction, and, in more severe cases, symptoms consistent with clinical depression. Gender differences, socioeconomic background, and school environment are identified as moderating factors that influence the intensity and manifestation of academic stress. The study further discusses protective factors, including supportive family relationships, effective coping strategies, school-based psychological counseling, and balanced academic workloads, which can mitigate the adverse effects of academic pressure. Practical implications are proposed for educators, school psychologists, and policymakers, emphasizing the need for curriculum reform, mental health literacy programs, and early identification of at-risk students. The study concludes that a holistic, prevention-oriented approach—integrating psychological support with educational policy—is essential to safeguarding adolescent mental health while maintaining academic achievement. Recommendations for future research include longitudinal designs and cross-cultural comparisons to better understand the long-term consequences of academic pressure on youth development.

Keywords: Academic Pressure, Adolescent Mental Health, Anxiety, Academic Stress, Psychological Well-being

THE IMPACT OF MANAGEMENT PROCESS AUTOMATION ON THE SPEED AND QUALITY OF MANAGERIAL DECISION-MAKING IN BUSINESS ORGANIZATIONS

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ABSTRACT
Management process automation, driven by robotic process automation, artificial intelligence, and integrated enterprise software, is reshaping how organizations gather information, evaluate alternatives, and reach managerial decisions. This study examines the impact of process automation on two dimensions of managerial decision-making: speed and quality. Speed refers to the time elapsed between the identification of a decision problem and the selection of a course of action, while quality refers to the accuracy, consistency, and long-term effectiveness of the decision reached. Based on a review of recent academic and industry literature, the study finds that automation accelerates decision-making primarily by reducing data-processing time, standardizing routine choices, and providing real-time dashboards that shorten the information-gathering phase. Regarding quality, automation improves consistency and reduces human bias in structured, data-rich decisions, but its benefits are less clear-cut in tasks requiring subjective judgment, ethical reasoning, or interpersonal sensitivity, where perceived fairness and trust may decline. The study also identifies organizational structure as a moderating factor: centralized firms tend to automate decisions under uncertainty to strengthen top-level control, while decentralized firms apply automation mainly to stable, routine operations. The paper concludes that management process automation offers substantial gains in decision speed and, under the right conditions, in decision quality, but organizations must actively manage communication gaps, employee trust, and the balance between automated and human judgment to realize these benefits sustainably.
Keywords: Process Automation, Managerial Decision-Making, Decision Speed, Decision Quality, Business Process Management

1. INTRODUCTION
Organizations today operate in environments characterized by rapid technological change, growing data volumes, and heightened competitive pressure. In this context, the speed and quality of managerial decisions have become key sources of competitive advantage. Management process automation, encompassing robotic process automation (RPA), workflow management systems, artificial intelligence (AI), and machine learning (ML), has emerged as a central mechanism through which organizations attempt to accelerate and improve decision-making. Industry surveys indicate that a large share of business leaders are actively expanding automation initiatives, with a substantial proportion of managerial tasks expected to be automated in the near future.

Despite the growing adoption of automation technologies, questions remain regarding their actual effect on the two core dimensions of managerial decision-making examined in this study: the speed with which decisions are reached, and the quality of the decisions produced. While automation is widely assumed to shorten decision cycles by eliminating manual data handling, its impact on decision quality is more contested, particularly for decisions involving uncertainty, ethical considerations, or interpersonal judgment. This study aims to synthesize existing research and provide a structured discussion of how process automation influences managerial decision-making, the conditions under which its benefits are maximized, and the risks organizations should manage during implementation.

2. DEVELOPMENT
2.1. Theoretical Background
Business process management (BPM) research has long been concerned with improving process performance through the design and automation of organizational workflows. Automation initiatives, such as robotic process automation and blockchain-based systems, have historically produced measurable performance gains, including cost reductions and significant time savings in specific operational areas.

More recently, the integration of AI techniques, including machine learning, natural language processing, computer vision, and predictive analytics, with traditional RPA has extended automation beyond routine, rule-based tasks toward more complex, semi-structured decision environments. This shift is often described as a move from simple task automation toward intelligent process automation, in which systems not only execute predefined steps but also support or partially substitute human judgment.

From a decision-making perspective, automation can be understood as an intervention that changes the information environment in which managers operate. By providing faster access to structured data, predictive insights, and standardized recommendations, automated systems alter both the cognitive demands placed on decision-makers and the organizational processes through which decisions are validated and implemented.

2.2. Impact on the Speed of Managerial Decision-Making

The most consistently reported benefit of management process automation is a reduction in the time required to reach a decision. Automated systems reduce the time managers spend collecting, cleaning, and interpreting data, allowing information to be delivered in near real time through dashboards and predictive analytics tools. This is particularly significant in operational and tactical decisions, such as inventory management, scheduling, and resource allocation, where automation enables continuous monitoring and rapid adjustment. Reports on business process automation adoption suggest that a large share of routine managerial tasks can be substantially automated, freeing managerial attention for higher-level, less structured decisions and thereby indirectly increasing the overall pace of organizational decision-making.

However, the acceleration effect is not uniform across all types of decisions. For decisions that require the integration of automated outputs with tacit knowledge, negotiation, or cross-functional coordination, the net gain in speed may be reduced, since managers must still interpret automated recommendations and reconcile them with contextual factors that systems cannot fully capture.

2.3. Impact on the Quality of Managerial Decision-Making

Automation's effect on decision quality is more nuanced than its effect on speed. For structured, data-intensive decisions, automation tends to improve quality by reducing calculation errors, enforcing consistent criteria, and enabling predictive analytics that anticipate outcomes before they occur. Prescriptive analytics, in particular, has been shown to support more efficient use of organizational resources by recommending optimal courses of action based on large datasets that would be impractical for a manager to process manually.

At the same time, research on algorithmic decision-making indicates that automated processes are sometimes perceived as less fair and less trustworthy than human-led processes, particularly in decisions requiring subjective judgment, such as performance evaluation or hiring. This perception gap can undermine employee cooperation and, indirectly, decision quality, even when the automated outcome is statistically sound. Furthermore, studies on corporate decision-making suggest that automating decisions in divisions facing high uncertainty can reduce the flow of informal, localized knowledge from mid-level managers to executives, potentially degrading the informational basis on which strategic decisions are made. This finding highlights an important trade-off: automation may strengthen top-level control while simultaneously weakening the quality of information available for complex, uncertain decisions.

2.4. Organizational and Implementation Considerations

The realized impact of automation on decision speed and quality appears to depend heavily on organizational structure and implementation strategy. Centralized organizations, characterized by top-down decision-making, tend to direct automation toward divisions facing greater uncertainty, using it to reduce dependence on the specialized knowledge of mid-level managers and to reinforce executive control. Decentralized organizations, in contrast, tend to apply automation to stable, routine, business-as-usual processes, preserving human judgment for decisions involving higher uncertainty. This distinction suggests that there is no single optimal automation strategy; rather, organizations must align automation deployment with their existing decision-making structures and risk tolerance.

A further consideration concerns the choice between full automation and human-AI augmentation. Evidence suggests that high-frequency, low-value tasks are well suited to full automation, where speed and consistency are paramount, whereas lower-frequency, higher-value decisions involving risk, ethics, or customer relationships benefit more from augmentation approaches, in which automated tools inform but do not replace managerial judgment. Organizations that explicitly design this division of labor between automated systems and human decision-makers appear better positioned to capture gains in both decision speed and decision quality without incurring the trust and communication costs associated with over-automation.

3. CONCLUSION

Management process automation has a clear and well-documented positive effect on the speed of managerial decision-making, primarily through faster data processing, real-time information access, and the standardization of routine choices. Its effect on decision quality is more conditional: automation improves consistency and analytical accuracy in structured, data-rich decisions, but can reduce perceived fairness, weaken informal knowledge flows, and complicate communication in decisions that require subjective judgment or that occur under high uncertainty. Organizational structure, whether centralized or decentralized, further shapes how and where automation is deployed, and consequently how its benefits and risks are distributed across managerial levels. For organizations seeking to improve managerial decision-making through automation, the evidence suggests that the most effective strategy is not maximal automation, but a deliberate combination of automation and human augmentation, calibrated to the frequency, structure, and stakes of each decision type. Future research should further examine the long-term effects of automation on managerial trust, communication quality, and organizational learning, using longitudinal and cross-cultural research designs.

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APPLICATION OF ARCHITECTURAL STRATEGIES IN THE DESIGN OF TRAILERS REST HUB IN MOKWA, NIGER STATE

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ABSTRACT
The efficiency of Nigeria's long-haul transport system is fundamentally linked to the welfare, safety, and operational conditions of truck drivers who sustain national supply chains. However, along critical transport corridors such as the mokwa axis of the Ilorin-Abuja–Minna network, the absence of formal, secure, and climatically responsive rest facilities has resulted in widespread reliance on informal roadside stops. These conditions expose drivers to thermal discomfort, fatigue, insecurity, and increased accident risks, while also contributing to traffic congestion and infrastructural inefficiencies. This study evaluates the role of integrated architectural design strategies in addressing these challenges through the development of a Trailer Rest Hub in mokwa, Niger State. It adopts a qualitative design research approach involving site analysis, literature review, and case study evaluation to identify context-responsive solutions. The study is grounded in three key theoretical frameworks: environmental comfort theory, bioclimatic design principles, and Crime Prevention Through Environmental Design (CPTED). Findings reveal that driver welfare is intrinsically linked to road safety and transport efficiency, with fatigue-related incidents exacerbated by inadequate rest infrastructure. Bioclimatic strategies such as optimal building orientation, shading devices, natural ventilation, thermal mass, and courtyard configurations demonstrate strong potential for enhancing thermal comfort in the hot-dry climate. Simultaneously, CPTED principles including natural surveillance, territorial reinforcement, and controlled access offer effective mechanisms for improving security and reducing vulnerability to crime. The study proposes an integrated design framework that synthesizes climatic responsiveness, security, and user-centred functionality into a cohesive architectural solution. This framework informs the conceptual master plan and schematic design of a Trailer Rest Hub that organizes vehicular movement, provides restorative environments for drivers, and ensures safety and operational efficiency.
Keywords: *Crime Prevention Through Environmental Design; traffic congestion; infrastructural inefficiencies; Trailer Rest Hub; context-responsive solutions.*

STUDY OF THE SORPTION KINETICS OF CU(II) IONS BY THE SODIUM SALT OF A MALEIC ACID–STYRENE–ALLYL PROPIONATE TERPOLYMER

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Abstract
A sodium salt of a maleic acid–styrene–allyl propionate terpolymer was synthesized and studied as a sorbent for the extraction of Cu(II) ions from aqueous solutions. The sorption behavior of Cu(II) ions was investigated depending on contact time, solution pH, and temperature, and the sorption capacity of the synthesized polymeric sorbent was determined. Particular attention was paid to the kinetics of Cu(II) ion sorption. The experimental data obtained at different sorption times were analyzed using the pseudo-first-order and pseudo-second-order kinetic models. The results showed that the sorption process is better described by the pseudo-second-order kinetic equation, with a high correlation coefficient of R^2 = 0.9876. The sorption rate constant and sorption capacity of the polymeric sorbent were calculated. UV–Vis spectra of the sorbent before and after Cu(II) ion sorption were also obtained. The spectral changes observed after sorption indicate the formation of a complex between Cu(II) ions and the active sorption sites of the polymer. The kinetic and spectroscopic results suggest that the sorption of Cu(II) ions is associated with a chemical interaction accompanied by complex formation between the sorption centers of the polymeric sorbent and Cu(II) ions. The obtained results demonstrate the potential of the synthesized polymeric salt as a sorbent for the removal of Cu(II) ions from aqueous solutions.
Keywords: Cu(II) ions; adsorption; polymer sorbents; heavy metals; wastewater treatment.

DİJİTAL FİTNESS KÜLTÜRÜ VE WELLNESS: SOSYAL MEDYA TEMELLİ EGZERSİZ İÇERİKLERİNİN FİZİKSEL VE PSİKOLOJİK İYİ OLUŞ ÜZERİNDEKİ ROLÜ

DIGITAL FITNESS CULTURE AND WELLNESS: THE ROLE OF SOCIAL MEDIA-BASED EXERCISE CONTENT IN PHYSICAL AND PSYCHOLOGICAL WELL-BEING

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ÖZET

Dijital teknolojilerin günlük yaşam ile ayrılmaz bir bütün haline gelmesi, fiziksel aktivite, fitness ve wellness anlayışlarında da elzem değişimlere neden olmuştur. Özellikle sosyal medya platformlarının yaygınlaşması, kişilerin egzersiz ve sağlıklı yaşam içeriklerine ulaşma şekillerini değiştirmiş; fitness uygulamaları, dijital antrenman öğeleri, akıllı ekipmanlar ve giyilebilir teknolojiler egzersiz süreçlerinin bir elemanı haline gelmiştir. Bu dönüşüm, kişilerin fiziksel aktiviteye yönelik motivasyonlarına destek olma ve egzersiz davranışlarını sürdürme yönünden önemli avantajlar sunarken, beden algısı ve psikolojik iyi oluş üzerinde çeşitli sonuçların ortaya çıkmasına da sebebiyet verebilmektedir. Bu çalışmanın hedefi, dijital fitness kültürünün fiziksel aktivite davranışı, egzersiz motivasyonu, beden algısı ve psikolojik iyi oluş ile ilişkisini wellness yaklaşımı neticesinde değerlendirmektir. Çalışmada konuya ilişkin güncel ve gerekli literatür analiz dijitalleşmenin fitness ve wellness alanındaki yansımaları ele alınmıştır. Literatür doğrultusunda sosyal medya platformlarının bilinçli kullanımının fiziksel aktiviteye yönelik motivasyonu destekleyebildiği, egzersiz içeriklerine ulaşımı kolaylaştırdığı ve kişilerin sağlıklı yaşam davranışlarına yönelik farkındalıklarını artırabildiği görülmektedir. Bu hususla sosyal medyada idealize edilen beden görünümlerinin sık olarak karşılaşılması, fiziksel görünüm mükemmeliyetçiliğini ve beden memnuniyetsizliğini artırabilecek bir olumsuzluk faktörü olarak değerlendirilmektedir. Düzenli fiziksel aktivite ve egzersizinse psikolojik iyi oluş, stres yönetimi, sosyal ilişkiler ve genel yaşam kalitesi açısından pozitif faydalar sağlayabildiği görülmektedir. Netice olarak dijital fitness kültürünün sadece fiziksel görünüm ve performans odağında değil, kişilerin fiziksel, psikolojik ve sosyal boyutlarını birlikte ele alan bütünsel bir wellness anlayışı içinde değerlendirilmesi gerektiği düşünülmektedir. Dijital teknolojilerin bilinçli kullanılması, sürdürülebilir fiziksel aktivite alışkanlıklarının geliştirilmesine ve sağlıklı yaşam davranışlarının desteklenmesine yarar sağlayabilir.
Anahtar Kelimeler: Dijital fitness, sosyal medya, fiziksel aktivite, egzersiz motivasyonu, wellness, psikolojik iyi oluş.

Abstract

The integration of digital technologies into daily life has led to significant changes in the understanding of physical activity, fitness, and wellness. In particular, the widespread use of social media platforms has changed the way individuals access exercise and healthy lifestyle content, while fitness applications, digital training content, smart equipment, and wearable technologies have become integral components of exercise processes. Although this transformation provides important advantages in terms of supporting individuals' motivation toward physical activity and maintaining exercise behaviors, it may also lead to various outcomes concerning body image and psychological well-being. The aim of this study is to evaluate the relationship between digital fitness culture and physical activity behavior, exercise motivation, body image, and psychological well-being within the framework of the wellness approach. In the study, relevant and up-to-date literature was reviewed, and the reflections of digitalization on the fields of fitness and wellness were examined. In line with the literature, the conscious use of social media can support motivation toward physical activity, facilitate access to exercise-related content, and increase individuals' awareness of healthy lifestyle behaviors. However, frequent exposure to idealized body images on social media may be considered a potential risk factor that can increase physical appearance perfectionism and body dissatisfaction.

Regular physical activity and exercise have also been found to provide positive benefits in terms of psychological well-being, stress management, social relationships, and overall quality of life. Consequently, digital fitness culture should be evaluated not only in terms of physical appearance and performance but also within a holistic wellness framework that considers individuals' physical, psychological, and social dimensions together. The conscious use of digital technologies may contribute to the development of sustainable physical activity habits and the promotion of healthy lifestyle behaviors.
Keywords: Digital fitness, social media, physical activity, exercise motivation, wellness, psychological well-being

GİRİŞ

Dijital Fitness Kültürü ve Sosyal Medya

Dijitalleşme, yalnızca teknolojik alanla sınırlı kalmayıp toplumsal ve kültürel yapılar üzerinde de önemli dönüşümlere neden olmaktadır. İletişim süreçlerinin farklılaşması, bilgiye ulaşma biçimlerinin değişmesi ve eğlence anlayışının yeniden şekillenmesi, toplumların kültürel dinamiklerini etkileyen başlıca unsurlar arasında yer almaktadır. Özellikle sosyal medya platformlarının yaygınlaşması ve çevrimiçi iletişim olanaklarının artması, bireyler arasındaki etkileşim biçimlerinin yanı sıra kişilerarası ilişkilerin niteliğinde de değişimler meydana getirmiştir. Bununla birlikte dijitalleşme, kültürel mirasa daha kolay ulaşılabilmesine ve farklı kültürler arasındaki iletişim ve etkileşimin güçlenmesine olanak sağlayarak olumlu sonuçlar da ortaya çıkarabilmektedir (Çakır & Dilci, 2024).

Dijital dönüşümün etkileri spor alanında da belirgin biçimde görülmektedir. Spor kuruluşlarının teknolojik gelişmeleri takip ederek mevcut yapılarını ve hizmet anlayışlarını yeniden şekillendirmeleri giderek daha önemli hale gelmiştir. Özellikle gençlerin geleneksel spor takip etme alışkanlıklarında dijitalleşmeye bağlı olarak önemli değişimler yaşanmış ve sporla ilgili içeriklerin dijital platformlar üzerinden takip edilmesi yaygınlaşmıştır. Bu doğrultuda spor kuruluşlarının, genç kuşağın dijital ilgi alanlarını ve e-spor gibi yeni spor tüketim biçimlerini dikkate alarak izleyiciyle etkileşim kurabilecek yeni yaklaşımlar geliştirmeleri gerekmektedir. Söz konusu dönüşüm, spor endüstrisinin gelecekte özellikle izleyici davranışları ve spor içeriklerinin tüketimi açısından nasıl bir yöne ilerleyebileceğine ilişkin önemli ipuçları sunmaktadır (Akkaya, 2023).

Teknolojik gelişmelerin fitness alanına yansıması ise kullanıcı ihtiyaçlarına göre farklı işlevleri bir arada sunabilen akıllı ekipmanların kullanımının yaygınlaşmasıyla dikkat çekmektedir. Birden fazla egzersizin gerçekleştirilebilmesine ve kullanıcıya özgü veriler doğrultusunda kişiselleştirilmiş hesaplamalar yapılabilmesine olanak sağlayan bu ekipmanlar, zaman içerisinde geleneksel fitness araçlarının kullanım biçimlerini dönüştürmüştür. Bunun yanında bireyin bedeni ve duyusal algılarıyla daha güçlü bir etkileşim kurmasını hedefleyen interaktif tasarım yaklaşımları, fitness mekânlarında kullanıcı deneyiminin yeniden şekillenmesine katkı sağlamıştır. Böylece iç mekânların düzenlenmesinde de dijital teknolojilere dayalı yenilikçi uygulamalar ön plana çıkmıştır. Fitness salonlarında kullanıcı deneyiminin geliştirilmesi ve sunulan hizmetlerin niteliğinin artırılması amacıyla akıllı ekipmanlar, sanal antrenörler, mobil uygulamalar ve yapay zekâ destekli analiz sistemleri gibi teknolojik uygulamaların kullanılmaya başlanması, bu dönüşümün önemli göstergelerindendir (Altan & Sever, 2025).

Sosyal medyanın fitness alanındaki etkisi yalnızca egzersiz içeriklerinin takip edilmesiyle sınırlı kalmamakta, bireylerin antrenörlere yönelik güven algıları ve egzersize ilişkin motivasyonları üzerinde de etkili olabilmektedir. 18-40 yaş arasındaki erkeklerle gerçekleştirilen bir çalışmada, fitness ve sosyal medya arasındaki etkileşimin giderek arttığı ve katılımcıların sosyal medya üzerinden içerik üreten antrenörleri, fitness salonlarında görev yapan antrenörlere kıyasla daha güvenilir bulabildikleri belirlenmiştir. Aynı çalışmada sosyal medyanın fitness egzersizlerine yönelik motivasyonu destekleyen bir unsur olduğu da ortaya konulmuştur. Bununla birlikte sosyal medya kullanmayan bireylerde ergojenik ürünlere yönelik daha düşük güven düzeyi ve bu ürünleri kullanmama eğiliminin bulunduğu görülmüştür. Elde edilen bulgular, sosyal medya ile fitness arasındaki etkileşimin bireylerin yalnızca egzersiz davranışlarını değil, ergojenik ürünlere ilişkin tutumlarını da etkileyebileceğine işaret etmektedir (Arıkan & Kılınç, 2025).

Sosyal Medya ve Fiziksel Aktivite Davranışı

Teknolojik gelişmelerin hız kazanmasıyla birlikte internet ve bilgisayarlar, bireylerin günlük yaşamlarının birçok alanında kullanılan temel araçlar haline gelmiştir. İnternetin sunduğu olanaklar sayesinde dünyada meydana gelen gelişmeleri takip etmek, güncel değişimlere uyum sağlamak, kişisel gelişimi desteklemek, eğitim ve iş yaşamındaki yeniliklere ulaşmak ve çeşitli eğlence faaliyetlerinden yararlanmak daha kolay ve hızlı bir biçimde gerçekleştirilebilmektedir. Bunun yanı sıra internet, bireylerin sosyal çevre oluşturmasına, farklı sosyal gruplarla etkileşim kurmasına ve kişilerarası iletişimi daha hızlı ve erişilebilir şekilde sürdürmesine olanak sağlamaktadır. Bu özellikleriyle dijital teknolojiler, bireylerin sosyal yaşamlarının önemli bir parçası haline gelmiştir (Karademir, 2017).

Sosyal medya platformlarının yaygınlaşması, sağlıklı yaşam ve fiziksel aktiviteye ilişkin içeriklerin bireylere ulaşmasını da kolaylaştırmıştır. Günümüzde özellikle ergenler, gençler ve yetişkinler; fiziksel olarak aktif olma, kilo kontrolü ve ideal beden görünümüne ulaşma gibi amaçlarla sosyal medya platformlarını yoğun biçimde kullanmaktadır. Sayfa yöneticileri ve içerik üreticileri tarafından hazırlanan görsel, video ve yazılı içerikler, bireylere fiziksel aktivite ve sağlıklı yaşam konusunda bilgi ve yönlendirme sunan teknoloji temelli araçlar olarak işlev görebilmektedir. Bu içeriklerin kullanıcılar tarafından düzenli olarak takip edilmesi, sosyal medyanın fiziksel aktivite davranışları açısından önemli bir iletişim ve etkileşim alanına dönüşmesine katkı sağlamaktadır (Ahraz ve ark., 2021).

Bununla birlikte sosyal medyanın fiziksel aktivite üzerindeki etkisi, kullanım biçimine bağlı olarak farklılık gösterebilmektedir. Bilinçli ve kontrollü sosyal medya kullanımı, bireylerin fiziksel aktiviteye yönelik motivasyonlarını destekleyebilmekte; spor kulüplerine katılım, grup egzersizlerine dahil olma ve açık hava etkinliklerine iştirak etme gibi yollarla bireylerin sosyal yaşama katılımını da artırabilmektedir. Fitness ile düzenli olarak ilgilenen bireyler üzerinde yapılan değerlendirmelerde, sosyal medya bağımlılığının egzersiz alışkanlıkları üzerinde belirgin bir olumsuz etki oluşturmadığı görülmüştür. Bu durum, sosyal medya kullanımının kontrollü ve bilinçli biçimde gerçekleştirilmesinin olası olumsuz etkilerin sınırlandırılmasına yardımcı olabileceğini düşündürmektedir (Akt; Kusan, 2025).

Fiziksel aktivitenin bireylerin hem fiziksel hem de psikolojik sağlığı açısından taşıdığı öneme rağmen, bu konudaki bilgi eksikliği ve teknolojik gelişmelerin beraberinde getirdiği hareketsiz yaşam biçimi önemli bir sorun oluşturmaktadır. Fiziksel aktivitenin sağlık üzerindeki koruyucu etkilerinin yeterince bilinmemesi ve günlük yaşamda daha az hareket edilmesi, bireylerin çeşitli sağlık riskleriyle karşı karşıya kalmasına neden olabilmektedir. Özellikle diyabet, osteoporoz, obezite, kardiyovasküler hastalıklar ve hipertansiyon gibi kronik hastalıkların toplumdaki yaygınlığında fiziksel hareketsizliğin önemli bir rol oynadığı belirtilmektedir (Cengiz & Delen, 2019).

Sosyal Medya ve Egzersiz Motivasyonu

Sosyal medya platformları, geniş kitlelere kısa sürede ulaşabilme ve bireyleri ortak içerikler etrafında bir araya getirebilme özellikleri sayesinde günümüzde önemli bir iletişim aracı haline gelmiştir. Toplumun çeşitli gelişmeler hakkında bilgilendirilmesi, etkinliklerin duyurulması, tanıtım faaliyetlerinin yürütülmesi ve destekleyici iletişim süreçlerinin oluşturulmasında sosyal medyadan yoğun biçimde yararlanılmaktadır. Özellikle ulusal ve uluslararası ölçekte gerçekleştirilen büyük spor organizasyonlarında sosyal medya; etkinliklerin tanıtılması, geniş kitlelere duyurulması ve izleyici desteğinin artırılması açısından önemli bir işlev üstlenmektedir. Kitle iletişim teknolojilerindeki gelişmelerin spor alanına yansıması, bireylerin spor faaliyetlerini takip etme ve bu faaliyetlerle etkileşim kurma biçimlerinde de değişiklik meydana getirmiştir. Geçmişte radyo aracılığıyla maçların takip edilmesinden günümüzde karşılaşmaların canlı yayınlar ve çevrimiçi platformlar üzerinden izlenebilmesine uzanan bu dönüşüm, bireylerin spor deneyimini daha erişilebilir ve etkileşimli hale getirmiştir. Böylece sporun bireylerde oluşturduğu heyecan ve mutluluk duygularının farklı dijital kanallar aracılığıyla daha yoğun biçimde yaşanması mümkün olmuştur. Sağlık ve sosyal etkileşim açısından taşıdığı önem nedeniyle spora yönelik toplumsal ilginin özellikle son yıllarda giderek arttığı görülmektedir (Akbulut & Taş, 2025).

Sosyal medyanın fiziksel aktivite ve sağlıklı yaşam davranışları üzerindeki etkisi ise kullanım biçimine göre farklılaşabilmektedir. Amaçlı ve bilinçli sosyal medya kullanımının fiziksel aktivite düzeyini destekleyebildiği, kişilerarası iletişimi güçlendirebildiği ve stresle başa çıkma süreçlerine katkı sağlayabildiği belirtilmektedir.

Buna karşın aynı kullanım biçiminin sağlıklı beslenme davranışları açısından her zaman olumlu sonuçlar ortaya çıkarmadığı görülmektedir. Özellikle adölesanlarda sosyal medyanın hangi amaçla kullanıldığı, kullanım süresi ve kullanım sıklığı, sağlıklı yaşam biçimi davranışları üzerinde hem olumlu hem de olumsuz yönde etkiler oluşturabilmektedir. Bu nedenle adölesanlara ve ebeveynlere yönelik sağlıklı yaşam eğitimlerinde sosyal medyanın uygun, kontrollü ve bilinçli kullanımına ilişkin konuların da ele alınması önem taşımaktadır (Avan, 2024).

Öte yandan sosyal medya ile egzersiz arasındaki ilişki her zaman tek yönlü bir etki biçiminde ortaya çıkmamaktadır. Sosyal medya bağımlılığı yüksek bireylerde düzenli egzersiz yapmanın internet kullanımını azaltmak yerine artırabileceğine ilişkin bulgular bulunmaktadır. Başka bir ifadeyle, fiziksel aktivite ve egzersiz düzeyi yükseldikçe bireylerin internet ortamında daha fazla zaman geçirme eğilimi gösterebildikleri ileri sürülmektedir. Bu durum, egzersiz davranışı ile dijital medya kullanımı arasındaki ilişkinin yalnızca sosyal medyanın egzersizi teşvik etmesi üzerinden değerlendirilmemesi gerektiğini; iki davranış arasındaki etkileşimin karşılıklı ve daha karmaşık bir yapıya sahip olabileceğini göstermektedir (Yüzer ve ark., 2025).

Fitness İçerikleri ve Beden Algısı

Fitness ve spor kültüründe beden algısı, bireylerin fiziksel görünüşlerini değerlendirme biçimlerinin yanı sıra belirli spor dallarının ortaya çıkardığı bedensel özelliklerle de şekillenebilmektedir. Sporcuların sahip oldukları fiziksel özellikler, ilgilendikleri branşın gerektirdiği performans ve beden yapısına bağlı olarak farklılık gösterebilmektedir. Örneğin jimnastikçiler daha düşük yağ oranına sahip ve daha ince bir fiziksel görünüme yönelirken, boks sporcularında daha belirgin kas yapısı ön plana çıkabilmektedir. Benzer şekilde futbolcularda atletik vücut yapısı dikkat çekerken, yüzücülerde geniş omuzlar ve gelişmiş üst ekstremite kasları daha belirgin olabilmektedir. Bu durum, spor branşlarının bireylerin beden algısı ve fiziksel görünüm beklentileri üzerinde farklı etkiler oluşturabileceğini göstermektedir (Uzun, 2025).

Bedenin belirli fiziksel ölçütler doğrultusunda şekillendirilmesine yönelik toplumsal beklentiler, fitness kültürünün bireylerin günlük yaşamındaki konumunu da güçlendirmiştir. Günümüzde bireylerin bedenlerini toplum tarafından ideal olarak kabul edilen görünüme yaklaştırma isteği, fitness faaliyetlerinin yalnızca fiziksel sağlık amacıyla değil, aynı zamanda sosyal yaşamın bir parçası olarak değerlendirilmesine neden olabilmektedir. Bedenin sosyal ilişkilerde ve bireyin kendisini ifade etmesinde önemli bir unsur olarak görülmesi, Turner'ın "bedenselleşmiş toplum" kavramıyla ilişkilendirilebilmektedir. Bununla birlikte medya araçlarının fitness ve vücut geliştirme kültürünün yaygınlaşmasındaki rolü de dikkat çekmektedir. Küresel ölçekte büyüyen spor endüstrisi ile kitle iletişim araçlarının etkileşimi, beden ve fitness kültürünün ekonomik ve kültürel bir endüstri içerisinde yeniden üretilmesine katkı sağlamaktadır. Bu yaklaşım, kültürün kitle iletişim araçları ve ekonomik sistemler aracılığıyla bir tüketim alanına dönüştüğünü savunan Frankfurt Okulu'nun görüşleriyle de örtüşmektedir (Durmaz & Özcan, 2021).

Fitness içerikleri ve beden odaklı sosyal medya paylaşımları, kaslı bir vücuda sahip olma arzusunun yaygınlaşmasında da etkili olabilmektedir. Kaslı bir beden başlangıçta aktif ve sağlıklı yaşamın göstergesi olarak algılanabilse de kas geliştirme hedefinin aşırıya taşınması bireyin fiziksel ve psikolojik sağlığı açısından çeşitli riskler oluşturabilmektedir. Özellikle kas gelişimini hızlandırmak amacıyla steroid kullanımına başvurulması, karaciğer ve böbreklerde hasar oluşma riskini artırabilmektedir. Bunun yanında steroid kullanımının psikolojik sağlık açısından da olumsuz sonuçlarla ilişkili olduğu; depresif belirtiler, duygu düzenleme güçlükleri ve düşük öz güven gibi sorunlarla bağlantı gösterebildiği belirtilmektedir (Hamurcu, 2023).

Bununla birlikte fiziksel aktivitenin beden algısı üzerindeki etkileri her zaman olumsuz bir çerçevede değerlendirilmemelidir. Özellikle farklı fiziksel engel durumlarına sahip bireylerin uygun fiziksel aktivitelere katılım göstermesi, bireyin kendi bedenine ilişkin algısının olumlu yönde değişmesine ve toplumsal aidiyet duygusunun güçlenmesine katkı sağlayabilmektedir. Fiziksel etkinliklere katılım sonucunda bireyin kendisine ilişkin imajının olumlu yönde gelişebildiği ve günlük yaşamda karşılaşılan stresle baş etme becerisinin desteklenebildiği belirtilmektedir. Bunun yanı sıra bireyin fiziksel durumuna ve gereksinimlerine uygun olarak planlanan aktivitelerin ödemin azaltılması, ağrı yönetimi ve doku iyileşmesinin desteklenmesi gibi fiziksel yararlar sağlayabileceği ifade edilmektedir (Murathan & Kartal, 2021).

Egzersiz ve Psikolojik İyi Oluş

Psikolojik iyi oluş, bireyin yaşam içerisinde karşılaştığı varoluşsal güçlüklerle başa çıkabilme ve yaşamını anlamlı amaçlar doğrultusunda sürdürebilme kapasitesiyle ilişkilendirilmektedir. Kişisel gelişimin desteklenmesi, yaşamda anlamlı hedeflerin oluşturulması ve diğer bireylerle nitelikli ilişkiler kurulması, psikolojik iyi oluşun temel bileşenleri arasında değerlendirilmektedir (Telef, 2021).

Bireyin fiziksel görünümüne ilişkin değerlendirmeleri de psikolojik iyi oluş üzerinde belirleyici olabilmektedir. Özellikle fiziksel görünüm açısından mükemmeliyetçi beklentilerin benimsenmesi, kişinin kendisini sürekli olarak yetersiz hissetmesine ve fiziksel özelliklerinden memnuniyet sağlayamamasına yol açabilmektedir. Fiziksel görünüm mükemmeliyetçiliği, bireyin kendisinden veya başkalarından fiziksel açıdan kusursuz olma beklentisi içerisinde olmasıyla karakterize edilmektedir. Bu yaklaşım, kişinin bedenini sürekli eleştirmesine, beden imajından memnuniyetsizlik yaşamasına ve kendisini diğer bireylerle karşılaştırmasına neden olabilmektedir. Dolayısıyla söz konusu tutumların psikolojik iyi oluş üzerinde olumsuz sonuçlar doğurabileceği belirtilmektedir. Bununla birlikte fiziksel görünüm ile psikolojik iyi oluş arasındaki ilişkinin her birey için olumsuz yönde olmadığı da görülmektedir. Kendi fiziksel görünümüyle daha barışık olan ve sağlıklı yaşam biçimini benimseyerek düzenli fiziksel aktivite gerçekleştiren bireylerin kendilerini daha olumlu değerlendirebildikleri ve psikolojik açıdan daha iyi hissedebildikleri ifade edilmektedir. Bireyin fiziksel görünümüne ilişkin beklenti ve tutumlarının benlik saygısı, özgüven ve genel yaşam doyumu üzerinde de etkili olabileceği belirtilmektedir (Pakyardım ve ark., 2024).

Egzersiz davranışının psikolojik iyi oluş üzerindeki olumlu etkilerinde yalnızca egzersizin varlığı değil, egzersizin düzenliliği ve bireyin farkındalık düzeyi de önem taşımaktadır. Yaşın ilerlemesiyle birlikte egzersiz yapma sıklığındaki ve bilinçli farkındalık düzeyindeki artışın psikolojik iyi oluşun olumlu yönde gelişmesine katkı sağladığı görülmektedir. Araştırma bulguları, düzenli egzersizin yanı sıra egzersiz sıklığının artmasının da bilinçli farkındalık ve psikolojik iyi oluş üzerinde olumlu etkiler oluşturabileceğine işaret etmektedir (Çelik & Akgün, 2024).

Egzersizin bireyin yaşamındaki konumunun psikolojik sonuçlar açısından da önem taşıdığı görülmektedir. Egzersizi yalnızca belirli bir amaca ulaşmak için gerçekleştirilen bir etkinlik olarak değil, yaşam biçiminin bir parçası olarak benimseyen bireylerin özerklik, yeterlik ve ilişki kurma gibi temel psikolojik ihtiyaçlarının daha yüksek düzeyde karşılandığı belirtilmektedir. Bu bireylerin söz konusu ihtiyaçlarının, egzersize sosyalleşme, fiziksel uygunluk kazanma veya yaşamında değişiklik oluşturma amacıyla katılan bireylere kıyasla daha fazla karşılandığı görülmektedir. Öte yandan egzersize yalnızca sağlığı koruma amacıyla yönelen bireylerin mental iyi oluş düzeylerinin, egzersizi yaşam biçiminin bir parçası haline getiren bireylere göre daha düşük olduğu bildirilmiştir. Egzersizi yaşam biçimi olarak benimseyen bireylerin mental iyi oluş düzeylerinin, sosyalleşme, fiziksel uygunluk veya yaşamında değişiklik oluşturma amacıyla egzersiz yapan bireylerden de daha yüksek olduğu belirlenmiştir (Öner, 2019).

Fitness ortamında fiziksel aktiviteye katılan bireylerin psikolojik iyi oluşları ile sağlıklı yaşam davranışları arasındaki ilişki de dikkat çekmektedir. Fitness katılımcılarının psikolojik iyi oluş ve sağlıklı yaşam biçimi davranışlarının egzersize yönelik sağlık inançları üzerindeki etkisinin incelendiği bir araştırmada, olumlu psikolojik iyi oluş düzeyi ve sağlıklı yaşam davranışlarının egzersizin sağlık üzerindeki etkilerine ilişkin farkındalığı güçlendirdiği belirlenmiştir. Araştırmada fitness katılımcılarının sağlık sorumluluğu, psikolojik iyi oluş, egzersize yönelik sağlık inancı, fiziksel aktivite, manevi gelişim, beslenme, stres yönetimi ve kişilerarası ilişkiler açısından yüksek düzeylere sahip oldukları tespit edilmiştir. Bu bulgular, fitness katılımcılarının sağlıklı yaşam davranışları ile ruhsal sağlık düzeylerinin olumlu bir görünüm sergilediğini ve egzersizin sağlık üzerindeki yararlarına ilişkin farkındalıklarının yüksek olduğunu göstermektedir. Dolayısıyla egzersizin sağlık üzerindeki olumlu etkilerine yönelik inancı güçlü olan bireylerin, fiziksel aktivitenin sağlık açısından sağlayabileceği yararların daha fazla farkında oldukları söylenebilir (Aydın, 2024).

Fiziksel Aktivite ve Wellness

Wellness kavramı, bireyin yalnızca fiziksel sağlığını değil, aynı zamanda mutluluk, öğrenme, toplumsal ilişkiler, çalışma yaşamı, maneviyat ve fiziksel aktivite gibi yaşamın farklı alanlarına ilişkin algı ve deneyimlerini kapsayan geniş bir yaklaşımı ifade etmektedir.

Bu doğrultuda wellness, beden ve zihinsel sağlığın birbirinden bağımsız unsurlar olarak değil, sürekli etkileşim içerisinde bulunan dinamik bir bütün olarak değerlendirilmesini gerektirmektedir. Bireyin farkındalığının gelişmesiyle birlikte şekillenen bu yaklaşımda stres yönetimi de dahil olmak üzere yaşam tarzını oluşturan farklı bileşenlerin genel refah ve yaşam kalitesi üzerindeki rolü ön plana çıkmaktadır (Akt; Çiğdem, 2024).

Wellness, sağlığın yalnızca hastalıkların bulunmaması şeklinde değerlendirilmesinin ötesine geçen ve sağlığın olumlu yönlerini merkeze alan bir yaklaşım olarak ele alınmaktadır. Bu kapsamda sağlık ve wellness; fiziksel, sosyal, duygusal, ruhsal ve zihinsel boyutların bir arada değerlendirilmesini gerektirmektedir. Özellikle stresin yoğun olduğu yaşam koşullarında bireyin sağlığını koruyabilmesi ve yaşam kalitesini sürdürebilmesi açısından bu boyutların bütüncül biçimde ele alınması önem taşımaktadır. Dolayısıyla wellness uygulamalarının temelinde bireyin farklı yaşam alanlarını kapsayan ve genel iyilik halini desteklemeyi amaçlayan bütüncül bir anlayış bulunmaktadır (Ayçeman, 2014).

Fiziksel aktivitenin wellness yaklaşımı içerisindeki yeri, bireylerin boş zamanlarını aktif ve verimli biçimde değerlendirmeleriyle de ilişkilendirilebilir. Boş zamanların fiziksel ve sosyal açıdan etkinliklerle değerlendirilmesi, bireysel gelişimin yanı sıra toplumsal yaşam üzerinde de çeşitli olumlu sonuçlar ortaya çıkarabilmektedir. Aktif boş zaman etkinlikleri fiziksel sağlığın geliştirilmesine, ruhsal sağlığın korunmasına ve bireylerin sosyal ilişkilerinin güçlendirilmesine katkı sağlayabilmektedir. Bunun yanında bireysel beceri ve yeteneklerin geliştirilmesi, yaratıcılığın desteklenmesi, mutluluk düzeyinin artırılması ve çalışma performansının iyileştirilmesi gibi bireysel kazanımlar da sağlayabilmektedir. Toplumsal açıdan değerlendirildiğinde ise ekonomik hareketliliğin desteklenmesi, sosyal dayanışma ve bütünleşmenin güçlendirilmesi, yaşam kalitesinin yükseltilmesi ve bireylerin eğitimsel ve duygusal gereksinimlerinin karşılanması gibi katkılar sunabilmektedir. Ayrıca aktif boş zaman faaliyetleri, bireylerin heyecan ve macera gereksinimlerini karşılamalarına da olanak sağlayarak wellness anlayışının yaşamın farklı boyutlarına yayılmasına katkıda bulunmaktadır (Akt; Gürsoy & Sevin, 2021).

Dijital Fitness Kültürünün Wellness Üzerindeki Rolü

Fitness ve wellness kavramları, bireyin sağlığını ve yaşam kalitesini destekleyen çeşitli bileşenler bakımından birbirleriyle yakından ilişkili olmakla birlikte birbirinin eş anlamlısı değildir. Fitness; genel sağlığın desteklenmesi, hastalıklardan korunma ve bilişsel işlevlerin geliştirilmesi gibi çeşitli yararlar sağlayabilmekte, aynı zamanda bireylerin boş zamanlarını sosyal açıdan daha tatmin edici etkinliklerle değerlendirmelerine olanak sunabilmektedir. Fitness düzeyinin artırılmasının hastalık ve erken ölüm riskinin azaltılmasıyla ilişkili olduğuna yönelik kanıtlar bulunmasına rağmen fitness kavramının doğrudan sağlık veya wellness ile özdeşleştirilmemesi gerekmektedir. Sağlık ve wellness, fiziksel boyutun yanı sıra sosyal, psikolojik ve diğer yaşam alanlarını da kapsayan daha geniş kavramlardır. Bu nedenle fitness, sağlık ve wellness ile güçlü bir ilişkiye sahip olmakla birlikte bu kavramların tamamını tek başına karşılayan bir yapı değildir (Eraslan ve ark., 2020).

Dijital teknolojilerin fitness alanına dahil olması, bireylerin egzersiz süreçlerini planlama ve takip etme biçimlerinde de değişiklik meydana getirmiştir. Günümüzde piyasada çok sayıda fitness uygulamasının bulunması, bireylerin kendi ihtiyaçlarına uygun uygulamayı belirlemesini ve doğru içerikleri seçmesini zaman zaman güçleştirebilmektedir. Bununla birlikte teknolojik olanakların yaygınlaşması, bireylere günlük, haftalık veya yıllık hedefler belirleyerek egzersiz süreçlerini daha düzenli biçimde takip etme imkânı sunmaktadır. Giyilebilir teknolojiler ve akıllı ürünler tarafından sunulan çeşitli hedefler ve meydan okumalar da bireylerin egzersiz sürecindeki motivasyonlarını destekleyen unsurlar arasında yer alabilmektedir (Özcan, 2023).

Dijital dönüşümün etkileri yalnızca bireysel fitness uygulamalarıyla sınırlı kalmayıp spor salonlarının fiziksel ve teknolojik yapısına da yansımaktadır. Günümüzde spor salonları, sağlık bilimindeki gelişmelerin, dijital teknolojilerin ve kullanıcı deneyimine yönelik tasarım yaklaşımlarının kesiştiği önemli mekânlar haline gelmiştir. Piyasada bulunan etkileşimli, ergonomik ve kişiselleştirilebilir teknolojiler, spor salonlarının hem fiziksel alanlarını hem de sundukları hizmetleri yeniden yapılandırmalarına olanak sağlamaktadır. Özellikle ekipman teknolojilerindeki gelişmeler, fitness mekânlarının dönüşümünde belirgin bir rol üstlenmektedir.

Biyometri ve dijital teknolojilerdeki ilerlemeler sonucunda InBody cihazları, Fit3D tarayıcılar ve TRX MAPS gibi sistemlerin spor salonlarında kullanılması, kullanıcı deneyimini çeşitlendiren ve salonların tercih edilmesini destekleyen teknolojik uygulamalar arasında değerlendirilmektedir (Krenn, 2020).
Spor salonlarında kullanılan dijital teknolojilerin bir diğer önemli unsuru ise görsel ve etkileşimli ekranlardır. Dijital ekranların yaygınlaşması, fitness mekânlarının daha modern bir görünüme kavuşmasına katkı sağlarken aynı zamanda üyelerin egzersiz sırasında motivasyonlarını desteklemek amacıyla da kullanılmaktadır. Bu teknolojiler aracılığıyla kullanıcıların egzersiz sürecine ilişkin çeşitli bilgileri takip edebilmesi ve görsel uyaranlardan yararlanabilmesi, spor salonlarında kullanıcı deneyiminin geliştirilmesine katkı sağlayabilmektedir. Böylece dijital teknolojiler yalnızca fitness ekipmanlarının işlevlerini değiştirmekle kalmamakta, aynı zamanda spor salonlarının genel atmosferini ve bireylerin egzersiz deneyimini de yeniden şekillendirmektedir (Yeler, 2021).

SONUÇ

Dijitalleşmeyle birlikte fitness ve wellness alanlarında bireylerin egzersize ulaşma, fiziksel aktiviteye katılma ve egzersiz motivasyonlarını sürdürme biçimleri önemli ölçüde değişmiştir. Sosyal medya, dijital fitness uygulamaları ve akıllı teknolojiler; fiziksel aktiviteyi destekleme, egzersiz konusunda farkındalık oluşturma ve psikolojik iyi oluşa katkı sağlama açısından önemli fırsatlar sunmaktadır. Bununla birlikte bilinçsiz sosyal medya kullanımı ve ideal beden algısının yaygınlaşması, bireylerde beden memnuniyetsizliği ve gerçekçi olmayan fiziksel görünüm beklentileri oluşturabilmektedir.
Bu doğrultuda dijital fitness kültürünün yalnızca fiziksel görünüm ve performans üzerinden değil, bireyin fiziksel, psikolojik ve sosyal iyi oluşunu kapsayan bütüncül bir wellness anlayışı içerisinde değerlendirilmesi gerekmektedir. Dijital teknolojilerin bilinçli ve dengeli kullanılması, bireylerin düzenli fiziksel aktivite alışkanlığı geliştirmesine, egzersiz motivasyonunu korumasına ve yaşam kalitesini desteklemesine katkı sağlayabilir. Dolayısıyla dijital fitness kültürünün temel amacı, yalnızca daha fit bir bedene ulaşmak değil, sürdürülebilir ve sağlıklı bir yaşam biçimini desteklemek olmalıdır.

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SPOR YOLUYLA GÜÇLENME: ÖZEL GEREKSİNİMLİ BİREYLERİN BAĞIMSIZ YAŞAM VE SOSYAL KATILIMINDA SPORUN ROLÜ

EMPOWERMENT THROUGH SPORT: THE ROLE OF SPORT IN PROMOTING INDEPENDENT LIVING AND SOCIAL PARTICIPATION AMONG INDIVIDUALS WITH SPECIAL NEEDS

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ÖZET

Özel gereksinimli bireyler için spor; fiziksel gelişim ile birlikte psikolojik ve sosyal gelişimlerini destekleyen önemli bir amaç ve araçtır. Düzenli yapılan fiziksel aktivite ve sportif etkinlikler; bireylerin fiziksel uygunluklarını artırırken öz güven, öz yeterlilik ve özerklik yeterliliklerini gelişmesini sağlamaktadır. Özellikle bireyin ihtiyaçlarına uygun olarak planlanan spor etkinlikleri, günlük yaşamda yaptıkları fiziksel aktivitelerini daha bağımsız bir şekilde yapmalarına yardımcı olmaktadır (Kalyon, 1994).Sporun sağladığı kazanımlar yalnızca fiziksel gelişimle sınırlı kalmayıp. Takım sporları ve grup temelli egzersiz ve etkinlikler, özel gereksinimli bireyler için farklı insanlarla iletişim kurmasına, arkadaşlık ilişkileri geliştirmesine, sosyalleşmelerine ve grup içerisinde sorumluluk almasına fırsat sunmaktadır. Bireylerin toplum içerisinde daha aktif rol almalarına ve asosyalliğin azalmasına katkı sağlamaktadır. Ayrıca sportif başarılar, bireyin kendine olan güvenini artırarak yaşamın diğer alanlarında da daha fazla sorumluluk üstlenmesine katkı sağlayabilmektedir (Tekkurşun vd., 2018).

Sonuç olarak spor, özel gereksinimli bireylerin sadece fiziksel uygunluk düzeyini destekleyen ve geliştiren bir etkinlik değil; bağımsız yaşam becerilerini, psikolojik iyilik halinin desteklenmesi ve topluma sosyal katılım açısından önemli bir gelişim aracıdır (İlhan, 2008). Bu nedenle özel gereksinimli bireylerin sportif etkinliklere erişimini kolaylaştıracak uygun ortamların oluşturulması ve bireysel farklılıkları dikkate alan kapsayıcı spor programlarının tanınması ve yaygınlaştırılması büyük önem taşımaktadır (Kabasakal, 2007).

Anahtar Kelimeler: Özel gereksinimli birey, Bağımsız Yaşam, Spor psikolojisi, Sosyal gelişim.

ABSTRACT

For individuals with special needs, sport serves as an important means and objective for supporting not only physical development but also psychological and social development. Regular physical activity and participation in sporting activities enhance individuals' physical fitness while contributing to the development of self-confidence, self-efficacy, and autonomy. In particular, sports activities planned in accordance with individual needs can help individuals perform physical activities and tasks of daily living more independently (Kalyon, 1994).The benefits of sport are not limited to physical development. Team sports and group-based exercises and activities provide individuals with special needs opportunities to communicate with others, develop friendships, socialize, and assume responsibilities within a group. Such activities contribute to enabling individuals to take a more active role in society and reducing social isolation. Furthermore, sporting achievements can enhance individuals' self-confidence and encourage them to assume greater responsibility in other areas of life (Tekkurşun et al., 2018).In conclusion, sport is not merely an activity that supports and improves the physical fitness levels of individuals with special needs; it is also an important developmental tool for promoting independent living skills, psychological well-being, and social participation in society (İlhan, 2008). Therefore, creating appropriate environments that facilitate access to sporting activities for individuals with special needs, as well as recognizing and expanding inclusive sports programs that take individual differences into account, is of great importance (Kabasakal, 2007).

Keywords: Individuals with Special Needs, Independent Living, Sport Psychology, Social Development

GİRİŞ

Özel Gereksinim Kavramı ve Spor

Özel gereksinimli birey kavramı, farklı tür ve düzeylerde yetersizliklere sahip bireyleri kapsayan geniş bir çatı kavramdır. Bu bireyler, sahip oldukları yetersizliklerin türü ve düzeyine bağlı olarak tipik gelişim gösteren bireylerden farklı biçimde görme, işitme, öğrenme, hareket etme ve algılama alanlarında çeşitli sınırlılıklarla karşılaşabilmektedir. Söz konusu sınırlılıkların niteliği ve derecesi, bireylerin öğrenme süreçlerini, davranışlarını ve çevreleriyle etkileşim biçimlerini de farklılaştırabilmektedir (Martin, 2013). Özel gereksinimli çocuklar, çeşitli nedenlere bağlı olarak fiziksel, mental, psikolojik, emosyonel ve sosyal yeteneklerini farklı derecelerde kaybetmiş bireylerdir. Bu durum nedeniyle toplumsal yaşama uyum sağlamada ve günlük gereksinimlerini karşılamada güçlük yaşayabilirler. Farklı düzeylerde ve çeşitli şekillerde korunma, bakım, rehabilitasyon, danışmanlık ve destek hizmetlerine ihtiyaç duyarlar. Engellilik türleri; ortopedik engellilik, görme engellilik, işitme engellilik, dil ve konuşma engeli, zihinsel engellilik ve süreğen hastalıklara bağlı engellilik şeklinde sınıflandırılmaktadır (Soysal ve Aslan, 2025).

Özel Eğitim Hizmetleri Yönetmeliği'ne (2006) göre özel gereksinim türleri; zihinsel yetersizlik, işitme yetersizliği, görme yetersizliği, ortopedik yetersizlik, dil ve konuşma güçlüğü, otizm, özel öğrenme güçlüğü, birden fazla yetersizlik, dikkat eksikliği ve hiperaktivite bozukluğu ile üstün yetenek olarak sınıflandırılmaktadır. Farklı yetersizlik alanları kapsamında geniş bir çerçevede ele alınan özel gereksinimli bireyler, diğer bireyler gibi çeşitli gelişim alanlarını destekleyebilecek ve toplum içerisindeki yerlerini anlamlandırabilecek etkinliklere ihtiyaç duyabilmektedir. Bu bağlamda, bireyin bedensel, zihinsel ve düşünsel yönleri arasındaki uyumu destekleyen; bireyin içinde bulunduğu toplumla sağlıklı, verimli ve dengeli ilişkiler geliştirmesine katkı sağlayan beden eğitimi ve spor alanı önem kazanmaktadır (Özdenk, 2018; Keleş ve Pepe, 2025).

Spor; bireyin doğal çevresini beşeri çevreye dönüştürürken kazandığı becerileri geliştirmesine olanak sağlayan, belirli kurallar çerçevesinde araçlı veya araçsız, bireysel ya da grup halinde gerçekleştirilen bir etkinliktir. Boş zaman faaliyeti olarak yapılabildiği gibi profesyonel bir meslek olarak da sürdürülebilen spor; bireyi sosyalleştiren, toplumla bütünleşmesini sağlayan, fiziksel ve ruhsal gelişimine katkıda bulunan, rekabet, dayanışma ve kültürel özellikleri barındıran bir olgudur (Yetim, 2000). Özel gereksinimli bireylerin fiziksel, psikolojik ve sosyal gelişimlerini destekleyen önemli bir araçtır. Düzenli olarak gerçekleştirilen sportif etkinlikler; kas kuvvetinin geliştirilmesine, aerobik kapasitenin artırılmasına, hareket kabiliyetinin desteklenmesine ve bireylerin yaşam kalitelerinin yükseltilmesine katkı sağlamaktadır. Bunun yanı sıra spor, özel gereksinimli bireylerin sosyal yaşama katılımını kolaylaştırarak toplumsal uyum süreçlerini desteklemekte ve bireylerin genel refah düzeylerinin gelişmesine olanak sunmaktadır. Bu doğrultuda, özel gereksinimli bireylerin spor faaliyetlerine aktif katılımının teşvik edilmesi, ihtiyaçlarına uygun ve erişilebilir spor ortamlarının oluşturulması ve mevcut sportif olanakların çeşitlendirilerek yaygınlaştırılması büyük önem taşımaktadır. Böylece spor, yalnızca fiziksel gelişimi destekleyen bir etkinlik olmaktan öte, özel gereksinimli bireylerin bağımsız yaşam becerilerini, sosyal katılımlarını ve yaşamdan aldıkları doyumu güçlendiren kapsayıcı bir araç olarak değerlendirilebilir (Avcı, 2019).

Fiziksel Güçlenme

Özel gereksinimli bireylere yönelik olarak uyarlanan veya özel olarak tasarlanan çeşitli spor branşları bulunmaktadır. Bu spor branşları, özel gereksinimli bireylerin ruhsal ve fiziksel açıdan olumlu kişilik özellikleri kazanmalarına katkı sağlamaktadır. Bunun yanı sıra, söz konusu branşlar bireylerin sosyal ve bilişsel gelişimlerinin yanı sıra motorik özelliklerinin gelişmesine de destek olmaktadır (Kozak ve ark., 2019; İlhan ve ark., 2022; Di Palma ve ark., 2016).

*Kuvvet: Spor, özel gereksinimli bireyin fiziksel kapasitesini geliştirmesine ve günlük yaşamda ihtiyaç duyduğu hareketleri daha rahat yapabilmesine yardımcı olur.

*Dayanıklılık: Düzenli fiziksel aktivite, bireyin hareket sırasında daha az yorulmasını ve günlük yaşam içerisinde daha aktif olmasını destekler.

*Denge: Denge becerisinin gelişmesi, bireyin vücudunu daha kontrollü kullanmasına ve hareket ederken kendini daha güvende hissetmesine katkı sağlar.

Koordinasyon: Farklı hareketlerin birbiriyle uyumlu şekilde yapılmasını geliştirir. Bu durum, bireyin hem sportif etkinliklere hem de günlük yaşam becerilerine daha etkin katılmasına yardımcı olur değerlendirilmektedir (Kıral ve ark., 2023).

Psikolojik ve Sosyal Güçlenme

Beden eğitimi ve spor etkinlikleri, engelli bireylerin gerek sahip oldukları engeller nedeniyle yaşadıkları ruhsal durumun gerekse toplumun kendilerine yönelik tutumlarının bir sonucu olarak ortaya çıkabilen saldırganlık, öfke ve kıskançlık gibi duygularını kontrol etmelerine yardımcı olmaktadır (Kınalı, 2003).
*Özgüven: Bireyin kendi çabasıyla bir hareketi veya beceriyi gerçekleştirmesi, "yapabilirim" düşüncesini güçlendirerek kendisine olan güvenini artırabilir.
*Motivasyon: Spor sırasında belirlenen küçük hedeflere ulaşmak, bireyin yeni şeyler deneme ve fiziksel aktiviteye devam etme isteğini artırabilir.
*Öz yeterlilik: Bireyin kendi becerilerinin farkına varmasını ve karşılaştığı durumlarda kendi çözümünü üretebileceğine inanmasını destekler.
*Başarma: Spor ortamında elde edilen her gelişme, bireyin kendisini başarılı ve yeterli hissetmesine katkı sağlar. Bu deneyimler başka alanlarda da yeni hedefler oluşturmasına zemin hazırlayabilir.
*Bağımsız yaşam: Fiziksel becerilerin ve psikolojik güçlenmenin birlikte ilerlemesi, bireyin günlük yaşamda başkalarına duyduğu desteği azaltarak kendi yapabildiği işleri artırmasına katkıda bulunabilir.
*Sosyal aidiyet: Bir grupla birlikte spor yapmak, bireye yalnızca fiziksel aktivite fırsatı sunmaz; iletişim kurma, arkadaşlık geliştirme ve kendisini bir topluluğun parçası olarak hissetme fırsatı da sağlar değerlendirilmektedir (Kıral ve ark., 2023).
Özel gereksinimli bireyler açısından spor, yalnızca fiziksel becerilerin geliştirilmesine yönelik bir faaliyet olarak görülmemelidir. Spor; bireyin bedenini daha etkin ve verimli kullanmasına katkı sağlamasının yanı sıra özgüven kazanmasını, sahip olduğu becerilerin farkına varmasını, bağımsız hareket edebilmesini ve toplum içinde daha aktif bir şekilde yer almasını destekleyen çok yönlü bir süreçtir. Bu doğrultuda, fiziksel, psikolojik ve sosyal gelişim birbirinden bağımsız unsurlar olarak değil, birbirini tamamlayan ve destekleyen bütüncül alanlar olarak değerlendirilmelidir (Aitchison ve ark., 2022).

Fiziksel, Psikolojik ve Bağımsız Yaşam Kazanımları

Toplum içerisinde engelli bireylerin kendi gereksinimlerini karşılamaya çalışırken dışlanmalarının ve ayrımcılığa maruz kalmalarının temel nedenlerinden biri, kendilerine yönelik önyargılı tutumların bulunmasıdır. Söz konusu önyargılar, engelli bireylerin sosyal yaşamlarını olumsuz etkileyerek toplumla uyum sağlamalarını güçleştirmekte ve özgüvenlerinin olumsuz yönde etkilenmesine neden olabilmektedir. Engelli bireylere yönelik tutumlar, onların toplumla bütünleşme süreçlerini doğrudan etkileyebilmekte; her ne kadar bu tutumlar çoğunlukla olumlu olarak ifade edilse de uygulamada engelli bireyler çeşitli olumsuz tutum ve davranışlarla karşılaşabilmektedir (Akt: Vural ve ark., 2018).
Engelli bireylerin fiziksel ve ruhsal açıdan yaşadıkları gerilimden uzaklaşmaları ve yaşam koşullarına fiziksel olarak uyum sağlayabilmeleri amacıyla önerilen fiziksel aktivite ve spor uygulamalarının, engelli bireyler tarafından gerçekleştirilebileceği konusu uzun yıllar boyunca göz ardı edilmiştir. Spor, oyun ve yarışma şeklinde gerçekleştirilen fiziksel aktiviteler; engelli bireylerin rehabilitasyon süreçlerinde, sosyal yaşam içerisinde iletişim kurabilmelerinde ve yaşam doyumlarının artırılmasında etkili bir araç olarak değerlendirilmektedir (Hazar ve Koç, 2020).
Özel gereksinimli bireylerin spor ve fiziksel aktivitelere katılımı, yaşam kalitesinin yanı sıra psikolojik iyi oluşlarını da desteklemektedir. Spor, bireylerin özgüven ve öz yeterliliklerini geliştirerek kendilerini daha güçlü ve yeterli hissetmelerine katkı sağlamaktadır. Aynı zamanda karar verme becerilerini destekleyen sportif etkinlikler, bireylerin bağımsızlık duygularını güçlendirmekte ve günlük yaşamda daha özerk hareket etmelerine olanak sunmaktadır. Bununla birlikte spor; sosyal ilişkilerin geliştirilmesi, iletişim becerilerinin güçlendirilmesi ve bireylerin sahip oldukları yeteneklerin farkına varmalarını sağlayarak bağımsız yaşama hazırlanmalarında önemli bir araç olarak değerlendirilmektedir (Kıral ve ark., 2023; Karakullukçu ve Polat, 2023).

Sosyal Katılım, Engeller ve Kapsayıcı Ortamlar

Engelli olma durumu, "yeti yitimi" kavramı ile ifade edilmektedir. Günümüzde engelli bireyler sportif faaliyetlerde aktif olarak yer almaktadır.

Spor; fiziksel, ruhsal, zihinsel ve motor becerilerin geliştirilmesine katkı sağlayan, bireyin sosyal çevresiyle olan etkileşimini artıran biyolojik, eğitsel ve sosyal bir kavram olarak değerlendirilmektedir (İlhan, 2008). Spor, özel gereksinimli bireylerin sosyal yaşama katılımını destekleyen ve toplumsal engellerin aşılmasına katkı sağlayan önemli bir araçtır. Özellikle akranlarıyla aynı ortamda sportif etkinliklere katılmaları; iletişim becerilerinin gelişmesini, sosyalleşmelerini ve sosyal aidiyet duygularının güçlenmesini desteklemektedir. Bununla birlikte, erişilebilir spor alanlarının yetersizliği, sosyal önyargılar, akran kabulünün sınırlı olması ve uygun olmayan sportif ortamlar, bireylerin spora ve sosyal yaşama katılımının önünde engel oluşturabilmektedir. Bu nedenle kapsayıcı ve erişilebilir spor ortamlarının oluşturulması, özel gereksinimli bireylerin akranlarıyla kaynaşmasını ve toplumsal yaşama daha aktif katılmasını sağlayabilir (Danışlı, 2020; Karakullukçu, 2020). Araştırmacılar, boş zaman etkinliklerinin engelli bireylere olumlu sosyal etkileşimler kurma, sosyal ve iletişim becerilerini geliştirme, arkadaşlık ilişkileri oluşturma ve topluma aidiyet duygusu kazanma açısından çeşitli fırsatlar sunduğu sonucuna varmışlardır (Akt: Gürkan ve ark., 2021).

Bariyerler

Engelli bireyler açısından fiziksel farklılıklar bir sorun oluşturmasının yanı sıra, sosyal, ekonomik ve çevresel açıdan da çeşitli engellerle karşılaşmalarına neden olabilmektedir. Bu bireyler toplum içerisinde sosyalleşme süreçlerinde farklı tutum ve davranışlara maruz kalabilmekte, sosyal dışlanma yaşayarak ötekileştirilebilmektedir. Toplumla olan bağların zayıflaması ve toplumsal bütünleşmenin sağlanamaması, temel haklardan yararlanamama, ekonomik yetersizlikler ve eşitsizliklerin artması ile sosyal ilişkilerin olumsuz yönde etkilenmesi gibi birçok farklı durum, sosyal dışlanmaya neden olan unsurlar arasında yer almaktadır (Trani ve ark., 2020; Tartanoğlu, 2010; Islam, 2015; Abualghaib ve ark., 2019; Lestari ve Fajar, 2020).

Bu bağlamda ilk ve en görünür engel, çevresel ve fiziksel erişim engelidir. Spor salonları, soyunma odaları, okul bahçeleri, tuvaletler, açık spor alanları ve ulaşım sistemleri çoğu zaman bireysel farklılıkları olan grupları dikkate alınmadan planlanmaktadır. Rampa eksikliği, hissedilebilir yüzeylerin bulunmaması, yetersiz zemin düzenlemeleri, uygun yönlendirme sistemlerinin olmaması, görsel ve işitsel uyarı sistemlerinin eksikliği gibi durumlar özel gereksinimli grupların daha etkinliğe başlamadan dışlanmasına neden olabilmektedir (Özdemir, 2019). İkinci önemli engel ise, pedagojik ve program temelli engellerdir. Beden eğitimi öğretim programları çoğunlukla ortalama performans düzeyine sahip, tipik gelişim gösteren öğrencilere yönelik tasarlanmaktadır (Ennis, 2011). Yine aşağıda belirtilen durumlar da etken olabilmektedir:

*Ulaşım: Spor alanlarına güvenli ve erişilebilir ulaşımın olmaması, bireyin düzenli olarak spora katılımını zorlaştırabilir.

*Maliyet: Spor ücretleri, ulaşım giderleri ve ekipman masrafları ekonomik açıdan erişimi sınırlayabilir.

*Tesis erişimi: Fiziksel olarak erişilebilir olmayan spor tesisleri, bireyin spora katılımının önünde doğrudan bir engel oluşturabilir.

*Bilgi eksikliği: Uygun spor programlarının, başvuru olanaklarının veya desteklerin bilinmemesi, bireyin mevcut fırsatlardan yararlanmasını engelleyebilir (Engin,2021).

*Olumsuz tutumlar: Önyargı, dışlanma veya bireyin yapabileceklerinin küçümsenmesi, fiziksel engeller kadar spora katılımı da sınırlandırabilir (Efendioğlu ve Emir Öksüz, 2024).



Şekil 1. Aktivite Performansını ve Katılımı Etkileyen Faktörlerin Şeması (toplumsal katılımı etkileyen faktörler) (Christiansen C, Baum C. Occupational therapy: Performance, participation and well being, 2004; Akt: Akyürek, 2011)

Bu bağlamda, engellilerin karşılaştıkları sorunlara yönelik çözüm önerileri geliştirilirken; engellilerin ve ailelerinin yanı sıra toplumun, kamu kurumlarının, sivil toplum kuruluşlarının, yerel yönetimlerin ve üniversitelerin katkılarının yanı sıra ülke dışından sağlanabilecek desteklerin de dikkate alındığı bütüncül bir uygulamaya ihtiyaç duyulmaktadır. Toplumun tüm kesimlerinde meydana gelecek olumlu davranış değişiklikleriyle birlikte, çeşitli alanlardaki kapasiteleri gelişen engelli bireylerin toplumun her alanında daha aktif rol almaları, sahip oldukları güçlerin farkına varmaları, bağımsızlaşmaları ve kendilerini gerçekleştirmeleri mümkün olacaktır (Demirel, 2022).

Kolaylaştırıcılar

*Aile ve akran desteği: Yakın çevrenin teşvik edici yaklaşımı, bireyin spora başlamasını ve devam etmesini kolaylaştırır.
*Antrenör desteği: Bireyin özelliklerini ve ihtiyaçlarını dikkate alan antrenör, sporu daha güvenli ve sürdürülebilir hâle getirir.
*Uygun ekipman: Bireye uygun yardımcı ve sportif ekipmanların bulunması, spora aktif katılımı destekler.
*Erişilebilir bilgi: Spor olanakları ve programlar hakkında anlaşılır ve ulaşılabilir bilginin sunulması, bireyin fırsatlardan haberdar olmasını sağlar.
*Kurumlararası eşgüdüm: Sağlık, eğitim, spor ve sosyal hizmet kurumlarının birlikte hareket etmesi, bireyin ihtiyaçlarına daha bütüncül yanıt verilmesine yardımcı olur (Karakullukçu, 2020).

Özel Gereksinimli Bireyler İçin Sporda Kapsayıcı Ortam ve Önemi

Kapsayıcı eğitim "dezavantajlı grupta yer alan öğrencilerin diğer arkadaşlarıyla aynı sınıfta öğretim faaliyetlerini sürdürerek eğitimsel açıdan birliktelik oluşturmayı hedefleyen bir anlayış" kabul edilmektedir (Mutlu ve ark., 2026). Beden eğitimi ve spor dersi, bu açıdan eğitim programının tamamlayıcı bir unsuru olarak değerlendirilmektedir. Gelişmekte olan nesillerin zihinsel, fiziksel, sosyal, duygusal ve psikomotor gelişimlerine doğrudan katkı sağlamaktadır. Bu doğrultuda beden eğitimi ve spor dersi, özel gereksinimli bireylerin kendi ihtiyaçlarını karşılayabilen, bağımsız bireyler olarak yaşamlarını sürdürebilmeleri ve topluma uyum sağlayabilmeleri açısından eğitim programının önemli ve vazgeçilmez bir parçası niteliğindedir (Çalışkan, 2011).

Kapsayıcı spor; fiziksel uygunluk ve motor becerilerin gelişiminin yanı sıra öz güven, öz yeterlilik, bağımsızlık ve sosyal becerileri destekler. Özel gereksinimli ve diğer bireylerin aynı sportif ortamı paylaşması, akran ilişkilerini ve sosyal aidiyeti güçlendirerek toplumsal kabulü artırır. Bu nedenle kapsayıcı spor, spora erişimin ötesinde bağımsız yaşamı, sosyal katılımı ve toplumsal eşitliği destekleyen önemli bir araçtır (Pakiş ve Uzun, 2026). Kapsayıcı spor ortamlarının temel unsurları; erişilebilir tesis ve ekipmanlar, fırsat eşitliği, bireye uygun uyarlanmış etkinlikler, sosyal kabul, destekleyici eğitmen yaklaşımı ve güvenli ortamdır. Bu unsurlar, bireylerin farklı gereksinimlerine uygun şekilde spora aktif katılım göstermelerini kolaylaştırır (Panda ve Kaur, 2024; Shafik, 2025). Uyarlanmış Fiziksel Aktiviteler (Adapted Physical Activities, APA), özel eğitim gereksinimi bulunan bireylerin fiziksel aktivitelere katılımlarını artırmak ve sağlıklı bir yaşam sürmelerini desteklemek amacıyla geliştirilmiştir. Bu kapsamda hazırlanan programlar; bireylerin motor becerilerinin ve fiziksel uygunluk düzeylerinin geliştirilmesinin yanı sıra sosyal etkileşimlerinin ve genel sağlık durumlarının iyileştirilmesini amaçlamaktadır (Block, 2007).

Özel Gereksinimli Bireyler İçin Spor Yoluyla Güçlenme

Spor yoluyla güçlenme; özel gereksinimli bireylerin fiziksel, psikolojik, sosyal ve işlevsel açıdan gelişimini destekleyen bütüncül bir yaklaşımdır. Model, bireyi pasif bir katılımcı olarak değil; karar verebilen, becerilerini geliştiren ve toplumsal yaşama katılan aktif bir birey olarak ele alır (Vural ve Kıratlı, 2025; Bindesen, 2025).

Özel eğitime gereksinim duyan bireylerin eğitim sürecinde spor ve egzersiz, motor gelişim, sosyal uyum ve yaşam kalitesinin geliştirilmesine önemli ölçüde katkı sağlamaktadır.

Fiziksel aktivite ve spor, bu öğrencilerin kas ve koordinasyon gelişimini desteklemenin yanı sıra, özgüvenlerini artırmalarına, sosyal becerilerini geliştirmelerine ve günlük yaşamlarını daha bağımsız sürdürebilmelerine katkı sağlamaktadır. Bu durum, özel gereksinimli bireylerle doğrudan ilgilenecek öğretmen adaylarının spor farkındalıklarının yüksek olmasının ve kendi yaşamlarında aktif bir rol model sergilemesinin önemini ortaya koymaktadır (Bozali ve Civil, 2026).

Spor Yoluyla Güçlenmenin İşleyişi

Özel gereksinimli bireylerde spor yoluyla güçlenme, birbirini takip eden ve birbirini destekleyen bir süreç olarak düşünülebilir.

*Erişilebilir spor ortamı: Bireyin fiziksel, iletişimsel ve sosyal ihtiyaçlarına uygun bir spor ortamının oluşturulması, spora katılımın ilk adımıdır.

*Aktif spora katılım: Uygun koşullar sağlandığında birey spora daha düzenli ve aktif şekilde katılabilir. Bu da sürecin devamlılığını destekler.

*Fiziksel ve sportif becerilerin gelişmesi: Düzenli katılım; kuvvet, denge, dayanıklılık, koordinasyon ve sportif becerilerin gelişmesine katkı sağlar.

*Öz güven ve öz yeterliliğin artması: Birey geliştirdiği becerileri ve elde ettiği başarıları gördükçe kendi kapasitesine yönelik güveni güçlenebilir.

*Sosyal ilişkilerin güçlenmesi: Spor ortamı, bireyin iletişim kurmasına, arkadaşlık geliştirmesine ve grup içerisinde aktif rol almasına fırsat verir.

*Bağımsızlığın ve özerkliğin gelişmesi: Fiziksel ve psikolojik kazanımlar arttıkça bireyin kendi kararlarını alma, seçim yapma ve günlük yaşamını daha bağımsız sürdürme becerileri desteklenir.

*Toplumsal katılımın artması: Tüm bu kazanımların sonucunda birey yalnızca spor alanında değil, eğitim, sosyal yaşam ve toplum içerisindeki farklı etkinliklerde de daha aktif rol alabilir (Vural ve Kıratlı, 2025).

Güçlenen Birey

Özel gereksinimli bireyler açısından spor, yalnızca fiziksel becerileri geliştirmek için yapılan bir etkinlik değildir. Bireyin kendi kapasitesini keşfetmesini, karar süreçlerine katılmasını ve yaşamında daha bağımsız bir rol üstlenmesini destekleyen bir araçtır (Kıral ve Temur, 2023).

Bu nedenle spor uygulamalarında her bireye aynı yaklaşım yerine bireyin ihtiyaçları, ilgi alanları ve sahip olduğu beceriler dikkate alınmalıdır. Erişilebilir ve kapsayıcı ortamların oluşturulması, bireyin spora yalnızca ulaşmasını değil, aktif olarak sürecin içinde yer almasını sağlar (Çil ve ark., 2023).

Buradaki temel amaç, bireyi var olan sisteme uyum sağlamaya zorlamak değil; spor ortamını bireyin farklılıklarına ve ihtiyaçlarına göre düzenlemektir. Böylece spor; fiziksel gelişimin yanında özgüven, öz yeterlilik, bağımsızlık ve sosyal katılımı da destekleyerek "güçlenen birey" yaklaşımını ortaya çıkarır (Bindesen, 2025).

SONUÇ

Özel gereksinimli bireyler için spor, yalnızca hareket etmeyi sağlayan bir etkinlik değil, bireyin kendi potansiyelini keşfetmesine ve günlük yaşamda daha bağımsız hareket etmesine olanak sağlayan bir süreçtir. Düzenli ve uygun koşullarda gerçekleştirilen sportif etkinlikler; özgüvenin gelişmesine, sosyal ilişkilerin güçlenmesine ve bireyin toplumla daha aktif bir bağ kurmasına katkı sunmaktadır. Ancak bu katkıların ortaya çıkabilmesi için spor ortamlarının bireylerin farklılıklarını gözetmesi ve herkes için ulaşılabilir olması gerekmektedir.

Fiziksel çevre, ekonomik koşullar, uygun ekipman ve destek eksikliği gibi engellerin azaltılması; aile, akran ve uzmanların sürece dahil edilmesi spora katılımı güçlendirecektir. Bu açıdan spor, özel gereksinimli bireylerin yalnızca becerilerini geliştiren bir alan olarak değil, kendi kararlarını verebilmelerini, bağımsızlıklarını artırmalarını ve sosyal yaşamda daha görünür olmalarını destekleyen bir güçlenme alanı olarak ele alınmalıdır. Kapsayıcı spor uygulamalarının yaygınlaştırılması, bireylerin daha aktif, bağımsız ve yaşamın içinde yer alan bireyler olmalarına önemli katkılar sağlayacaktır.

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MACHINE LEARNING–BASED ASSESSMENT OF HEMATOLOGIC TOXICITY DURING CHEMORADIOTHERAPY FOR STAGE III CERVICAL CANCER

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ABSTRACT

Background: Concurrent chemoradiotherapy represents a standard therapeutic approach for locally advanced cervical cancer, but treatment-related hematologic toxicity may compromise treatment intensity, increase the need for dose modifications, and potentially affect oncologic outcomes. Serial laboratory parameters provide an accessible source of information for monitoring treatment tolerance, while machine-learning (ML) techniques may identify complex patterns within longitudinal clinical data that are difficult to recognize using conventional approaches alone.

Aim: To characterize longitudinal hematologic changes during platinum-based chemoradiotherapy in patients with stage III cervical cancer and to evaluate the ability of different machine-learning algorithms to classify treatment-related clinical patterns using routinely collected laboratory parameters.

Materials and Methods: This study included 45 patients with stage III cervical cancer treated between 2018 and 2023 at an oncology center in Western Romania. Serial measurements of neutrophils, leukocytes, lymphocytes, hemoglobin, thrombocytes, and creatinine were collected throughout treatment. Forty-two patients received cisplatin-based therapy and three received carboplatin. Four ML approaches were evaluated: Naïve Bayes (NB), Random Forest (RF), Decision Tree (DT), and TabPFN, a transformer-based model developed for small tabular datasets. The dataset was divided into 80% training and 20% validation subsets.

Results: Progressive hematologic deterioration was observed during treatment. Mean hemoglobin decreased from 12.18 ± 1.66 g/dL at baseline to 10.37 ± 1.88 g/dL at the fifth assessment. Leukocyte counts declined from 7.39 ± 2.62 to 3.48 ± 1.51 ×10⁹/L, while lymphocyte counts decreased markedly from 1.42 ± 0.76 to 0.48 ± 0.31 ×10⁹/L. Thrombocyte counts decreased from 301.28 ± 82.70 to 190.13 ± 107.05 ×10⁹/L, whereas creatinine showed only a comparatively modest increase. Significant longitudinal differences were observed for several hematologic parameters. In the ML analysis, Naïve Bayes, Random Forest, and Decision Tree achieved classification scores of 100%, while TabPFN achieved an accuracy of 88%.

Conclusions: Platinum-based chemoradiotherapy for stage III cervical cancer was associated with substantial longitudinal hematologic changes, particularly affecting hemoglobin, leukocyte, lymphocyte, and thrombocyte levels. Machine-learning algorithms showed high classification performance using routinely collected laboratory parameters, supporting their potential role in identifying treatment-related hematologic patterns. Nevertheless, the exceptionally high performance observed for several models in this relatively small cohort should be interpreted cautiously. Larger, independent and more heterogeneous datasets are required to establish whether ML-based approaches can reliably predict clinically relevant hematologic toxicity and contribute to individualized treatment monitoring.
Keywords: cervical cancer; machine learning; artificial intelligence; chemoradiotherapy; hematologic toxicity; predictive modeling; personalized oncology.

INDUCING THE FORMATION OF SOLO GARLIC BULB AT LOW ELEVATION OF INDONESIA BY APPYLING PLANT GROWTH REGULATORS ON VERNILIZED SEED MATERIALS

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ABSTRACT
Solo garlic, garlic with only one clove, has been used for medicine since ancient time. However, regardless of its benefit and good prices, this garli has not been produced commercially in Indonesia, due to lack of information on how to produce it. The overall goal of this experiment was to promote the formation of solo garlic at low elevation in Indonesia by treating different sources of plant materials with vernalization. Furthermore, the specific objective of the experiment were to compare the effect of different souces of plant materials, different period of vernalization, and their interaction on the growth and yield of garlic crops. The experiment, conducted at low elevation of Indonesia (10 m a.s.l.) from December 2025 to March 2026, used randomized complete block design, arranged in factorial (2 factors, 5 reps). The first factor was source of plant material (outer cloves of regular garlic, inner clove of regular garlic, and solo garlic). The second factor was vernalization regime (0, 3, 6 weeks of vernalization). Vernalized seeds grown in the field with 20 cm x 20 cm of row spacing. Data recorded included plant height, number of leaf, number of bulb, bulb diameter, bulb length, buld weight, and buld volume. The results showed that all crops produced bulb with only one clove, having different size and weight. The outer clove showed the highest number of leaf, bulb diameter, bulb weight, and bulb volume. Vernalization did not affect crop growth, but it improved the quality of garlic bulb produced. There was no significant effect of the interaction between plant materials and period of vernalization. It was concluded that the best plant material to promoted the formation of solo garlic at low elevation of Indonesia was outer clove of regular garlic. Finally, a 3-week vernalization was considered the best period to promote the formation of solo garlic.
Keywords: Seeds, Solo garlic, Vernalizlation.

SOME FIXED POINTS OF ENRICHED JAGGI-DASS TYPE *CONTRACTIONS BY KRASNOSELSKII ITERATIVE METHOD IN* BANACH SPACES

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Abstract
In the present idea, we introduce the enriched (k; a; b)-Jaggi-Dass contraction mapping on a Banach space. In particular, we discuss the existence and uniqueness of a fixed point of such a mapping in Banach spaces.Moreover; several results concerning some enriched mappings are established in Banach spaces.
Keywords: Banach spaces , enriched Jaggi-Dass contraction mapping, Krasnoselskii iterative method

EVALUATION OF TRICHODERMA SP. METABOLITE CONCENTRATIONS AGAINST BASAL STEM ROT DISEASE IN OIL PALM SEEDLINGS IN THE MAIN NURSERY

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Abstract
Oil palm (*Elaeis guineensis* Jacq) is one of the highest oil-yielding crops in the world. The cultivated area, production, and export of oil palm commodities in Indonesia continue to increase relative to other commodities in the plantation sub-sector. A major limiting factor in Indonesian oil palm production is the occurrence of basal stem rot disease caused by *Ganoderma* spp. This disease represents a primary obstacle to the development and increased production of oil palm in Asia. The objective of this study was to evaluate the secondary metabolites of *Trichoderma* sp. in controlling basal stem rot disease in oil palm seedlings during the main nursery phase. The study employed a Completely Randomized Design (CRD) with a single factor consisting of *Trichoderma* sp. secondary metabolite concentrations: K0 = 0 ppm, K1 = 100 ppm, K2 = 200 ppm, K3 = 300 ppm, and K4 = 400 ppm; the experiment involved five replications, with two plants per replication. Five-month-old DxP Yangambi PPKS oil palm seedlings were used. The results indicated that the application of *Trichoderma* sp. secondary metabolites at a concentration of 400 ppm showed potential for inhibiting basal stem rot disease by suppressing both disease incidence and disease severity. Furthermore, the 400 ppm concentration was the most effective at inducing resistance in the oil palm plants by stimulating the production of salicylic acid compounds.
Keywords: Disease incidence, disease severity, salycylic acid content

DIETARY PATTERNS IN ALBANIA: BETWEEN THE MEDITERRANEAN TRADITION AND NUTRITIONAL TRANSITION

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Abstract

Background: Diet and lifestyle are major determinants of health and contribute substantially to the prevention of chronic diseases. Albania has traditionally exhibited several characteristics of a Mediterranean dietary pattern; however, socioeconomic development, urbanization, and globalization have resulted in important changes in dietary habits. This study aimed to assess dietary intake and macronutrient distribution among adults living in Tirana.

Methods: A cross-sectional study was conducted among 1,000 adults aged 25–75 years residing in Tirana. Dietary intake during the preceding 12 months was assessed using a 66-item Food Frequency Questionnaire. Food composition tables were used to estimate total daily energy intake and the intake of proteins, fats, carbohydrates, cholesterol, and fatty acids. Dietary intake was also compared between men and women.

Results: Of the 1,000 participants, 513 (51.3%) were men and 487 (48.7%) were women, with a mean age of 49.95 ± 14.52 years. Mean daily energy intake was 2,713.19 ± 639.25 kcal. Men had significantly higher energy intake than women (2,878.12 ± 558.40 vs. 2,511.20 ± 665.47 kcal/day; $p<0.01$). Men also consumed significantly more protein (130.41 ± 25.87 vs. 113.59 ± 25.30 g/day), fat (118.80 ± 22.44 vs. 108.13 ± 24.94 g/day), and carbohydrates (319.73 ± 84.10 vs. 284.43 ± 97.06 g/day; $p<0.01$ for all). Carbohydrates, fats, and proteins contributed 44.61%, 37.43%, and 17.96% of total energy intake, respectively. Approximately 63% of total fat intake consisted of unsaturated fatty acids. Mean daily cholesterol intake was 511.82 ± 162.77 mg and was significantly higher among men than women ($p<0.01$).

Conclusions: Dietary patterns among adults in Tirana reflect an ongoing nutritional transition, characterized by relatively high energy and fat intake. Nevertheless, the substantial contribution of unsaturated fatty acids suggests that important features of the Mediterranean dietary pattern persist. Continued nutritional surveillance and promotion of healthy dietary habits are warranted in Albania.
Keywords: Albania, Mediterranean diet, macronutrients, energy intake.

GREEN ARCHITECTURE FEATURES AND PERCEIVED USERS' SATISFACTION IN NIGERIA'S RESORT FACILITIES

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ABSTRACT
The increasing focus on environmental sustainability has influenced contemporary resort design, prioritizing resource efficiency, environmental conservation, and well-being. This study examines the impact of green architecture features on user's satisfaction in resort facilities, with particular focus on how sustainable design strategies influence visitors' experiences. The study examines key green architectural elements, including daylighting, energy-efficient systems and sustainable building materials. Structured questionnaires were administered to resort visitors and hospitality personnel. Data were analysed to identify the relationship between sustainable architectural features and user satisfaction indicators including comfort, health, aesthetics, environmental awareness, and overall resort experience. Findings reveal that green architecture features contribute positively to user satisfaction by enhancing thermal comfort, visual quality, connection to nature, and perceptions of environmental responsibility. The study further indicates that guests increasingly value resorts that demonstrate commitment to sustainability, which positively influences their intention to revisit and recommend such facilities. The research concludes that the integration of green architecture principles extends beyond environmental benefits to serve as a strategic tool for improving user's experience. The study recommends the incorporation of comprehensive green design strategies in resort development for enhanced sustainability goals and higher levels of guest satisfaction.
Keywords: Environmental Sustainability, Green Architecture, Resort Facilities, Sustainable Design, User Experience.

1. INTRODUCTION
The global hospitality industry is under mounting pressure to reconcile guest comfort with environmental responsibility. Resorts, by their nature, are resource-intensive typologies, drawing heavily on energy for cooling and lighting, on water for landscaping and recreational facilities, and on materials sourced with little regard for their embodied environmental cost. In Nigeria, where resort development has expanded rapidly in response to a growing domestic leisure market, this tension is particularly visible, since many facilities are designed with imported conventions that pay little attention to climate, culture or long-term operating cost.

Green architecture offers a response to this tension. It refers to design and construction practices that minimise a building's negative impact on the environment while improving occupant health and comfort, through strategies such as passive cooling, daylighting, water-efficient fixtures, renewable energy integration and the use of locally sourced or low-impact materials. While the environmental case for green architecture is well established, its influence on how users actually experience and evaluate a building has received comparatively less attention in the Nigerian resort context, where studies have tended to focus on hotels and office buildings.

This gap matters because guest satisfaction is the primary driver of repeat patronage, positive word of mouth and, ultimately, the commercial viability of a resort. If green features measurably improve how visitors perceive comfort, aesthetics and their connection to the surrounding environment, then sustainability ceases to be a purely regulatory or ethical consideration and becomes a competitive strategy in its own right.

The study therefore sets out to examine the relationship between green architecture features and perceived user satisfaction in Nigerian resort facilities.

Specifically, it aims to identify the green architectural elements most present in the sampled resorts, to assess visitors' and staff perceptions of comfort, health, aesthetics and environmental awareness in relation to those elements, and to establish whether green features influence intention to revisit and to recommend the facility. The paper is organised into five sections: this introduction, a review of relevant literature and theory, the research methodology, a presentation and discussion of findings, and a conclusion with recommendations for practice and further research.

2. LITERATURE REVIEW

2.1 Green Architecture: Concepts and Principles

Green architecture, sometimes used interchangeably with sustainable or eco-architecture, is grounded in the broader idea of sustainable development, defined by the World Commission on Environment and Development as development that meets present needs without compromising the ability of future generations to meet theirs (Brundtland, 1987). Translated into building practice, this principle is expressed through strategies grouped under three broad concerns: energy efficiency, material sustainability and occupant well-being.

Climate-responsive design, an idea long associated with Olgyay's (1963) bioclimatic approach, emphasises that a building's form, orientation and envelope should respond to local climatic conditions rather than depend on mechanical systems to compensate for poor design decisions. In hot, humid climates such as much of Nigeria, this translates into deep overhangs, cross-ventilation, elevated floors, shaded openings and the use of thermal mass to moderate indoor temperature swings, all of which reduce reliance on air conditioning while improving comfort.

Material sustainability draws on the cradle-to-cradle philosophy articulated by McDonough and Braungart (2002), which argues that materials should be selected and specified with their full life cycle in mind, from extraction through use to eventual reuse or safe return to the environment. In the Nigerian context, this principle aligns naturally with vernacular building traditions that use locally available materials such as laterite, timber and thatch, which typically carry a lower embodied energy than imported alternatives and connect a building to its regional identity.

Green building rating systems such as LEED and BREEAM formalise many of these strategies into certifiable performance criteria covering energy, water, materials, indoor environmental quality and site sustainability. While formal certification remains uncommon among Nigerian resorts, the criteria embedded in these systems provide a useful checklist against which the presence and quality of green features can be assessed even in uncertified facilities.

2.2 Resort Facilities and Sustainable Design in Nigeria

Resorts differ from conventional hotels in that leisure, recreation and immersion in a natural or landscaped setting are central to the guest experience rather than incidental to it. This distinction matters for green design because it means the environmental quality of a resort, its greenery, natural light, air quality and visual connection to landscape, is not a peripheral amenity but part of the core product being offered to the visitor.

Studies of the Nigerian hospitality sector have generally found that sustainable design remains an emerging rather than mainstream practice, constrained by higher perceived upfront costs, limited availability of green-certified materials and a shortage of professionals trained in sustainable design methods. Where green features do appear, they tend to cluster around passive strategies that are relatively low-cost to implement, such as natural ventilation and daylighting, rather than higher-cost interventions such as renewable energy systems or greywater recycling. This pattern suggests that Nigerian resorts are more likely to achieve sustainability outcomes incrementally, through design decisions embedded in the building's basic form, than through discrete technological add-ons.

2.3 User Satisfaction in the Built Environment

User satisfaction in the built environment is commonly understood through the expectation-disconfirmation framework, which holds that satisfaction arises from the gap between what a user expects of an environment and what they perceive it to actually deliver (Oliver, 1980).

Applied to resort facilities, this suggests that guests who expect a resort to be comfortable, aesthetically pleasing and environmentally considerate will evaluate their stay favourably when the building's features meet or exceed those expectations, and unfavourably when they fall short.

Within hospitality research more broadly, satisfaction is frequently decomposed into dimensions such as tangibles, reliability, comfort and empathy, an approach popularised by the SERVQUAL model (Parasuraman, Zeithaml and Berry, 1988). For a physical facility such as a resort, tangibles and comfort are especially sensitive to architectural decisions: thermal comfort, acoustic quality, daylighting and visual access to greenery all fall within the direct control of the designer rather than the service staff.

A substantial body of environmental psychology research links exposure to natural elements with measurable improvements in occupant well-being. Ulrich's (1984) widely cited study of hospital patients found that a view of natural scenery was associated with shorter recovery times and reduced need for pain medication compared with a view of a wall, an early empirical anchor for what later researchers formalised as biophilic design, the deliberate incorporation of nature, natural light and organic form into the built environment (Kellert, Heerwagen and Mador, 2008). For resort facilities, where restoration and escape from everyday stress are part of the guest's motivation for visiting, this connection between nature exposure and perceived well-being is directly relevant to satisfaction outcomes.

2.4 Theoretical Framework

This study is anchored on two complementary theoretical positions. The first, Sustainable Development Theory, provides the broad justification for why green architecture matters, framing environmental performance and human well-being as mutually reinforcing rather than competing goals (Brundtland, 1987). The second, Biophilic Design Theory, explains the mechanism through which green features are expected to influence satisfaction, proposing that human beings have an innate affinity for natural systems and that environments which satisfy this affinity, through daylight, vegetation, natural materials and views of nature, produce measurable improvements in comfort, mood and perceived restoration (Kellert, Heerwagen and Mador, 2008). Read together, the two frameworks suggest that green architecture features are not merely a means of reducing a resort's environmental footprint but a direct pathway to the comfort, health and aesthetic outcomes that inform guest satisfaction.

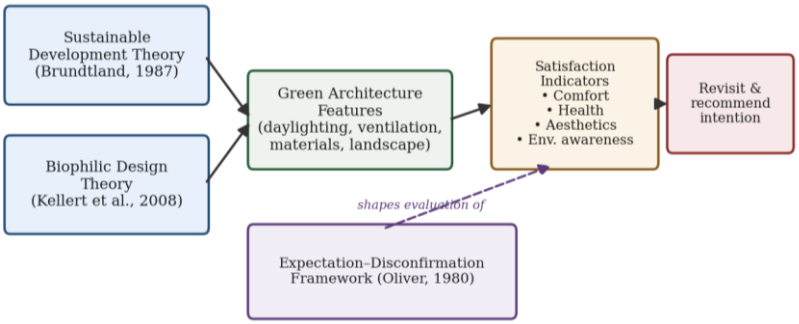


Figure 2. Theoretical framework linking Sustainable Development Theory and Biophilic Design Theory, through green architecture features, to guest satisfaction outcomes.

Source: author's construction.

2.5 Gap in the Literature

Existing Nigerian studies on green architecture have concentrated largely on office buildings, residential estates and, to a lesser extent, hotels, typically evaluating environmental or energy performance rather than user-perceived satisfaction. Where satisfaction has been studied in Nigerian hospitality facilities, it has generally been examined through service-quality dimensions such as staff responsiveness and pricing rather than through the physical, architectural attributes of the building itself. Resort facilities, with their heightened dependence on landscape and natural setting, remain particularly under-examined. This study addresses that gap by evaluating perceived satisfaction specifically in relation to green architectural features within Nigerian resort facilities.

3. METHODOLOGY

3.1 Research Design

The study adopted a quantitative, considered appropriate for capturing perceptions across a relatively large and dispersed population of resort visitors and staff within a limited data collection window. The design allowed the relationship between green architecture features and satisfaction indicators to be examined statistically rather than through in-depth case narratives, in keeping with the study's aim of establishing generalisable patterns rather than exploring a single facility in depth.

3.2 Study Area and Population

The study was conducted within selected resort facilities in Nigeria, purposively chosen to include a mix of coastal, urban and semi-rural settings so that the influence of climate and landscape context on green feature implementation could be reasonably captured. The population of interest comprised two groups: resort visitors, whose direct experiential judgement of comfort and aesthetics was the primary outcome of interest, and hospitality personnel, whose day-to-day familiarity with the building's operational performance offered a complementary, more technically grounded perspective.

3.3 Sampling Technique and Sample Size

A combination of purposive and convenience sampling was used to select the resort facilities and, within each facility, to recruit respondents. Purposive sampling ensured that only facilities incorporating at least some identifiable green architecture features, such as natural ventilation, extensive use of daylighting or landscaped courtyards, were included, while convenience sampling was applied to visitors and staff who were present and willing to participate during the data collection period. This combination balanced the practical constraints of accessing resort guests, who are typically present for short stays, against the need to ensure that respondents had meaningful exposure to the features under investigation.

3.4 Research Instrument

A structured questionnaire was the principal instrument for data collection, divided into sections covering respondent bio-data, awareness of green architecture concepts, perceived presence of specific green features within the resort, and satisfaction indicators comprising comfort, health, aesthetics, environmental awareness and overall experience. Satisfaction items were measured on a five-point Likert scale ranging from strongly disagree to strongly agree, allowing responses to be aggregated into mean satisfaction scores for each indicator. The instrument was reviewed by academic staff within the Department of Architecture for content validity before administration, and minor revisions were made to improve clarity and remove ambiguous wording.

3.5 Data Collection Procedure

Questionnaires were administered directly to consenting visitors and hospitality personnel at the selected resort facilities, with the researcher or trained assistants available on site to clarify items where necessary. Respondents were assured of anonymity and informed that participation was voluntary, in keeping with standard ethical practice for survey-based research involving human participants.

3.6 Method of Data Analysis

Completed questionnaires were coded and analysed using descriptive statistics, including frequencies, percentages and mean scores, to summarise respondent profiles and satisfaction ratings. Inferential techniques, including correlation analysis, were applied to examine the strength and direction of the relationship between the presence of green architecture features and each satisfaction indicator. This approach allowed the study to move beyond simple description to establish whether observed associations between green features and satisfaction outcomes were statistically meaningful.

4. RESULTS AND DISCUSSION

This section summarises the patterns emerging from the survey data. Figures are presented in general terms consistent with the study's abstract; where the paper is finalised for presentation, they should be substituted with the precise descriptive and inferential statistics computed from the collected dataset.

4.1 Respondents' Profile and Green Feature Awareness

The majority of respondents across the sampled facilities were resort visitors, with hospitality personnel forming a smaller complementary group. Awareness of the term green architecture was moderate among visitors and considerably higher among staff, who were more likely to have received some form of orientation on the facility's sustainability practices. Passive features, particularly natural lighting and ventilation, were the green elements most readily identified by respondents, consistent with the literature's observation that Nigerian resorts favour low-cost passive strategies over technologically intensive interventions.

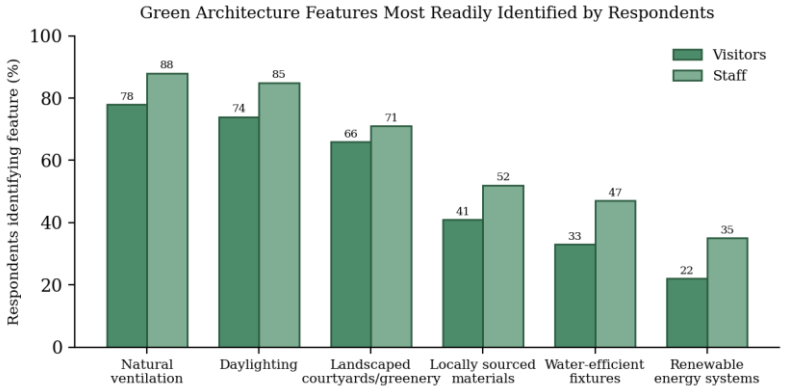


Figure 3. Green architecture features most readily identified by visitor and staff respondents. Values are an illustrative representation of the reported survey pattern, to be substituted with computed dataset statistics in the final paper.

Source: author's construction.

4.2 Green Architecture Features and Satisfaction Indicators

Across the satisfaction indicators measured, thermal comfort and visual quality returned the strongest positive associations with the presence of green architecture features, a pattern consistent with the climate-responsive design literature reviewed earlier, since shading, cross-ventilation and daylighting act directly on the sensory experience of a space. Respondents in facilities with visible landscaping, courtyards and unobstructed views of natural surroundings reported a stronger sense of connection to nature and rated the aesthetic quality of the environment more favourably than those in facilities with limited greenery.

Environmental awareness and perceptions of the resort's environmental responsibility were also positively associated with the presence of green features, suggesting that guests do not simply experience these features passively but actively interpret them as a signal of the facility's values and management priorities. This interpretive dimension appeared to extend to behavioural intention, with respondents who rated green features highly also expressing a stronger intention to revisit the facility and to recommend it to others, echoing the study's central premise that sustainability functions as more than an environmental safeguard.

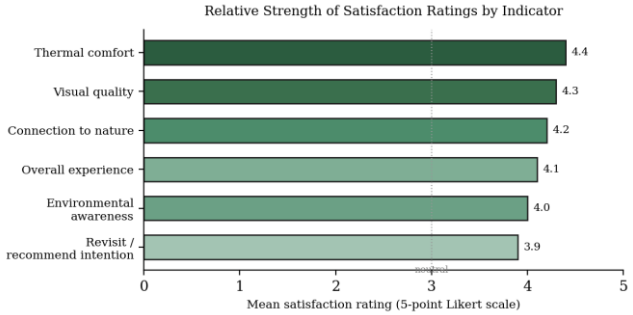


Figure 4. Relative strength of mean satisfaction ratings across indicators. Values are an illustrative representation of the reported survey pattern, to be substituted with computed dataset statistics in the final paper. Source: author's construction.

4.3 Discussion

Taken together, the findings support both theoretical strands underpinning the study. The strength of the association between passive climate-responsive features and comfort ratings affirms Olgyay's (1963) argument that climate-responsive form is not incidental to comfort but constitutive of it, while the link between visual and natural connection and satisfaction lends support to biophilic design theory's claim that exposure to natural elements produces measurable psychological benefit (Kellert, Heerwagen and Mador, 2008). The association between green features and revisit intention further situates the findings within the expectation-disconfirmation framework, since guests appear to interpret the presence of these features as exceeding a baseline expectation of a conventional resort, producing a favourable disconfirmation that translates into loyalty.

The findings also carry a practical implication that departs somewhat from how sustainability is often marketed within the Nigerian hospitality sector, namely as a cost-saving or regulatory-compliance measure aimed primarily at operators rather than guests. The evidence here suggests that green architecture features are directly legible to visitors and meaningfully shape how they evaluate their stay, which repositions sustainable design as a guest-facing value proposition rather than a purely operational one.

5. CONCLUSION AND RECOMMENDATIONS

This study set out to examine the relationship between green architecture features and perceived user satisfaction in Nigerian resort facilities. The findings indicate that green features, particularly passive strategies such as daylighting, natural ventilation and landscaped connection to nature, are positively associated with comfort, aesthetic appreciation, environmental awareness and, ultimately, guests' intention to revisit and recommend the facility. These results support the view that green architecture in resort design serves a dual function, advancing environmental performance while simultaneously acting as a strategic driver of guest experience and commercial competitiveness.

On this basis, the study recommends that resort developers and designers in Nigeria prioritise passive, climate-responsive strategies from the earliest stages of design rather than treating sustainability as an add-on feature, that vernacular and locally sourced materials be considered not only for their lower environmental cost but for the aesthetic and cultural value guests associate with them, and that resort operators communicate their sustainability practices more explicitly to guests, since the findings suggest that visible green features are actively interpreted and valued rather than passively experienced. For future research, the study recommends extending this line of inquiry to a larger, more geographically diverse sample of Nigerian resorts, and to comparative studies examining whether the satisfaction gains associated with green features differ across guest demographics or across coastal, urban and semi-rural resort typologies.

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EXPLORATION OF SUKUR INDIGENOUS CLIMATIC ADAPTATION STRATEGIES IN RESIDENTIAL BUILDING IN ADAMAWA STATE, NIGERIA

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ABSTRACT
Contemporary residential housing in Adamawa State, Nigeria, continues to rely on standardised concrete construction with limited consideration of the region's semi-arid climate, contributing to poor indoor comfort and growing dependence on mechanical cooling (Ajayi, Daramola, & Ayodele, 2024). This study examines how the indigenous construction logic of the Sukur Cultural Landscape, a UNESCO World Heritage Site in the Mandara Mountains, can inform more climate-responsive residential design. A qualitative case study design was used, combining architectural and spatial documentation with a structured interview and observation instrument administered to Sukur community elders, custodians, traditional builders, and residents. The instrument recorded siting and orientation practices, compound and courtyard arrangement, material sourcing, and occupants' own ratings of indoor thermal comfort and the perceived effectiveness of shading and compound clustering. No thermal data-logging instrumentation was available for this study; indoor thermal conditions are therefore represented through occupants' documented perceptions rather than instrument-measured temperature values.
Findings indicate that siting and orientation decisions in Sukur are deliberately managed to avoid direct morning solar penetration through entrances, that compounds are clustered at close spacing around shared courtyards which residents frequently associate with improved indoor coolness, and that shading features are consistently rated highly effective at blocking direct solar exposure. Residents describe indoor conditions during the hottest months as moderately warm but tolerable without mechanical cooling, with fans used only occasionally. Interviews also reveal an ongoing transition in construction practice from thatch to zinc roofing, and from single-room circular huts to multi-room rectangular forms alongside a clearly expressed community preference for retaining stone and mud-wall construction. These documented, perception-based findings are used to propose an indicative framework for translating Sukur's siting, clustering, shading, and material logic into contemporary residential housing in Adamawa State. The framework's performance claims are presented as propositions for future work rather than instrument-verified benchmarks.
Keywords: Hot-Dry Climate; Vernacular Housing; Sukur Architecture; Passive Cooling; Thermal Comfort Perception; Sustainable Residential Housing; Adamawa State.

1. INTRODUCTION
The relationship between building form and climate is a long-standing concern in architectural practice, reflecting the ongoing effort to create habitable environments that respond to local environmental conditions (Ajayi, Daramola, & Ayodele, 2024). The built environment remains a major contributor to global energy consumption, with space cooling, lighting, and ventilation demands accounting for a significant share of residential energy use (UNEP, 2022). In Nigeria, over-reliance on mechanical air conditioning in poorly climate-adapted housing has been repeatedly identified as a barrier to energy-efficient residential design (Ajayi, Daramola, & Ayodele, 2024; Kalu & Ogunnaike, 2025).
Adamawa State has experienced accelerating residential development driven by population growth. Most contemporary residential buildings adopt standardised concrete block construction with minimal climatic adaptation, resulting in overheated interiors and heavy reliance on air-conditioning. Before industrial materials became dominant, communities such as the Sukur people developed hillside settlements that responded directly to topography and climate.

The Sukur Cultural Landscape, inscribed on the UNESCO World Heritage List in 1999, is recognised for its integrated relationship between architecture, terrain, and social organisation (UNESCO World Heritage Centre, 2023; Re-Thinking the Future (RTF), 2024).

A recurring theme in recent Nigerian architectural research is that passive design orientation, controlled openings, shading, thermal mass, and natural ventilation consistently outperforms unmodified imported building forms in hot climates, yet remains inconsistently applied in practice (Kalu & Ogunnaike, 2025; Ajayi, Daramola, & Ayodele, 2024; Akubue & Adesina, 2023). This paper asks: how can the siting, clustering, shading, and material logic documented in Sukur inform sustainable residential housing design in Adamawa State? Given that instrumented thermal measurement was not available for this study, the paper approaches this question through architectural documentation and community-based interviews, translating the climatic reasoning embedded in Sukur vernacular construction as understood and practised by its own custodians and builders into a performance-oriented design framework.

2. LITERATURE REVIEW

2.1 Vernacular Architecture and Climate Responsiveness

Recent Nigerian and African studies affirm that vernacular and courtyard-based buildings in hot climates support passive cooling through orientation, shading, and compact clustering. Akubue and Adesina (2023) show that courtyard geometry and height-to-width ratios strongly influence natural ventilation potential in tropical Nigerian settlements, while Santos, Ferreira, and Lanzinha (2024) find that vernacular dwellings across African hot-climate regions consistently outperform unmodified 'modern' housing on occupant-reported comfort, particularly through thermal mass and shading rather than mechanical means. Ajayi, Daramola, and Ayodele (2024), in a systematic review of passive design options for Nigerian housing, similarly conclude that orientation, shading, and material choice remain the most consistently effective and most consistently under-applied strategies in contemporary residential practice.

2.2 Biophilic Integration and Well-Being

A parallel body of recent work links vegetative and courtyard-based design to occupant well-being. Abdulkadir and Olagunju (2023) report that direct experience of natural elements greenery, shaded courts, open sightlines improves occupant-reported comfort in Nigerian residential settings, a finding echoed by Agboola and Adedire (2023) in institutional buildings and synthesised across the wider literature by Kalu and Ogunnaike (2025). Taken together, these sources support treating Sukur's courtyard clustering and vegetation integration not only as thermal strategies but as contributors to occupant well-being, consistent with the socio-spatial patterns documented in this study.

2.3 Gaps in Current Research

Much of the recent literature on passive and vernacular design in Nigeria relies on simulation tools or on-site instrumentation to quantify performance (Akubue & Adesina, 2023; Ajayi, Daramola, & Ayodele, 2024). Comparatively little published work documents Sukur specifically through direct engagement with its own custodians and builders. This study addresses that gap using a documentation- and interview-based case study approach, consistent with the resources available for this research, and positions its contribution as a foundation for future instrumented verification rather than as a substitute for it.

3. STUDY CONTEXT: SUKUR CULTURAL LANDSCAPE

Sukur is a UNESCO World Heritage Site located on a terraced hillside in Madagali Local Government Area, Adamawa State, Nigeria, in the Mandara Mountains near the Cameroon border, at an elevation of approximately 1,045 metres above sea level and roughly 290 km from Yola (UNESCO World Heritage Centre, 2023; RTF, 2024). The site covers a total area of 1,942.50 hectares, with a core zone of 764.40 hectares and a buffer zone of 1,178.10 hectares. In December 1999, Sukur became Africa's first cultural landscape inscribed on the World Heritage List (UNESCO World Heritage Centre, 2023).

Historical accounts describe Sukur as a longstanding centre of iron smelting, trade, and political organisation dating to at least the sixteenth century, with a hierarchical settlement structure centred on the hilltop Hidi (chief's) palace (RTF, 2024).

The settlement lies within a semi-arid savannah climatic zone characterised by high daytime temperatures, dry-season extremes, marked diurnal temperature variation, and Harmattan winds. Field documentation for this study recorded a chief's residence compound at approximately 10°37′42"N, 13°23′57″E, at an elevation consistent with published figures for the site, sited atop a steep hillside within a cluster of five structures spaced roughly 2–4 m apart.

The residential structures are predominantly stone- and mud-walled, with roofing that as documented in interviews for this study (Section 4.4) has shifted from thatch toward zinc sheeting over residents' lifetimes. Compounds are clustered rather than standalone, centred on shared courtyards used for daily domestic and social activity. Dry-stone retaining walls stabilise the terraced hillside terrain without the use of mortar, consistent with descriptions of the wider Mandara highland building tradition (RTF, 2024).

4. DOCUMENTED AND PERCEIVED ENVIRONMENTAL PERFORMANCE OF SUKUR VERNACULAR HOUSING

4.1 Siting, Orientation, and Solar Control

Interview responses indicate that siting decisions in Sukur are shaped primarily by natural site constraints the steep, terraced hillside topography leaves limited buildable ground, and structures are positioned accordingly. On orientation, one respondent, a long-term resident and community elder, stated that an entrance gate should never face directly east, so that the low morning sun does not penetrate the interior space; the entrance may face any other direction provided this condition is met. This is a clear, deliberate solar-control rule embedded in local building practice, independent of any formal design guidance.

4.2 Compound Clustering, Courtyard Configuration, and Perceived Coolness

Field observation recorded compounds clustered closely together five structures within a single cluster, spaced approximately 2–4 m apart in the documented case. When asked to rate the effect of this clustering on the coolness of their home on a five-point scale (1 = Never, 5 = Always), the respondent selected 'Frequently' (4/5), indicating a consistently perceived though not universally absolute cooling benefit from close compound spacing. This is broadly consistent with recent literature on courtyard geometry and airflow in tropical Nigerian settings, which links closer, well-proportioned courtyard clustering to improved natural ventilation potential (Akubue & Adesina, 2023).

Building materials grass for thatch, mud for the dome/wall structure, and stone for walls are sourced directly from the surrounding landscape, minimising transport and processing inputs. This is consistent with the low-embodied-energy profile generally reported in the literature for unfired earth and stone construction relative to cement-based systems (Sapna & Anbalagan, 2023), though this study did not independently test or measure embodied energy for the sampled structures.

4.3 Shading Effectiveness and Occupant-Reported Thermal Comfort

Shading features were rated by the respondent as 'Very effective' (5/5) at blocking direct solar exposure. Indoor conditions during the hottest part of the day were rated 'Moderately hot' (3/5) on a five-point comfort scale, and described qualitatively as 'moderately okay, since it doesn't warrant direct use of external mechanical means of cooling.' During the coldest/rainy months, indoor conditions were described as tolerable without heating, though cold enough to prompt use of blankets. Additional cooling was reported as used only 'Occasionally,' limited to fans there was no reported use of air conditioning. Taken together, these self-reported ratings describe a dwelling residents regard as thermally workable without mechanical intervention, rather than one that eliminates heat stress altogether; this is a materially different and more defensible claim than a specific instrument-measured temperature reduction.

4.4 Socio-Spatial Continuity and Change

Interviews indicate that building practice in Sukur has changed within living memory in three respects: roofing material has shifted from thatch to zinc sheeting; hut form has shifted from circular to rectangular or square; and room configuration has shifted from single-room huts to compounds of two to three rooms under one roof. Despite these changes, the respondent confirmed that younger community members are still learning traditional building skills, and identified stone and mud/adobe walling but notably not thatch roofing as the elements of traditional practice that should be preserved and carried

into modern housing. This distinction, offered directly by a community custodian, suggests that any translation framework should treat wall material and massing as the primary heritage-performance assets to preserve, while treating roofing material as an area where the community itself has already adapted.

5. METHODOLOGY

5.1 Research Philosophy and Design

This study adopts an interpretivist research philosophy, on the basis that understanding how Sukur's building practices work and why they are practised as they are requires access to the meaning that community custodians and builders themselves attach to siting, materials, and form. The study employs a qualitative case study design, combining architectural and spatial documentation with community-based structured interviews, rather than an instrumented comparative design. This departs from the mixed-methods, instrument-based design originally proposed for this research; the change reflects the unavailability of thermal data-logging equipment during the fieldwork period, and is treated as a methodological limitation (Section 5.8) rather than a silent substitution.

5.2 Study Area

Fieldwork was conducted at Sukur, Madagali Local Government Area, Adamawa State, Nigeria, in the Mandara Mountains, at an elevation of approximately 1,045 m above sea level. Data collection covered two distinct compounds within the wider hillside settlement: the Hidi's (chief's) palace compound, documented at approximately 10°37′42″N, 13°23′57″E, and one additional resident compound within the same settlement cluster. Fieldwork was carried out in a single field visit, on 3rd August 2026, between 10:00 am and 4:30 pm.

5.3 Sampling Strategy

A purposive sampling strategy was used, targeting individuals with direct knowledge of Sukur building practice. A total of two interview respondents participated in the study, comprising one custodian the Hidi, interviewed at the palace compound and one long-term resident, interviewed at the second documented compound. Both of the two compounds documented for the study (the Hidi's palace and the additional resident compound) were also subjected to the architectural and spatial observation/documentation checklist described in Section 5.4.1. Participants were selected on the basis of availability and willingness to participate at the time of fieldwork.

5.4 Data Collection Methods

5.4.1 Architectural and Spatial Documentation

Each documented site was recorded using a field observation and documentation checklist covering site identification, GPS coordinates, compass bearing of the main façade, slope/topography description, position relative to surrounding structures, and compound/cluster characteristics (number of structures in cluster, approximate inter-structure spacing). Measurements were taken using a compass and measuring tape/pacing on site; a laser distance meter or data logger was not used.


(1)

(2)

Figure 1: Hidi's Court where chiefs and elders hold their meetings, Figure 2: A typical resident in Sukur Kingdom.

Photographic documentation was carried out using a phone camera, capturing general views, elevations, and construction details of the documented structures.

Hand sketches were used to record supplementary spatial information not readily captured photographically, including approximate floor plans of houses and other structures. A total of 12 distinct structures were documented across the two compounds.

5.4.2 Thermal Comfort Perception Assessment

In place of instrument-based thermal monitoring, this study used respondent self-report to assess indoor thermal conditions. The instrument included five-point Likert-scale items on: how the home feels during the hottest part of the day (1 = Very hot to 5 = Very cool); the effectiveness of shading features in blocking direct sun (1 = Not effective to 5 = Very effective); and the effect of compound clustering on the coolness of the home (1 = Never to 5 = Always). This approach follows the established practice, common in occupant-comfort research, of using structured subjective ratings where instrumented measurement is not feasible; it documents perceived comfort, not measured indoor temperature.

5.4.3 Material and Construction Observation

Material sourcing and preparation were recorded through direct questioning (e.g. "How are these materials sourced and prepared?") rather than through laboratory testing or a formal life-cycle assessment. Comparative embodied-energy figures cited in this paper (Section 4.2) are drawn from published literature (Sapna & Anbalagan, 2023) for context and are not original measurements from this study.

5.4.4 Structured Interviews

A structured interview schedule (Instrument A) was administered to Sukur community custodians, elders, and traditional builders, covering respondent profile, siting and orientation, compound arrangement and spatial density, courtyard configuration, lived thermal comfort, additional cooling methods, and continuity and change in building practice. Interviews began with a standard introductory consent script explaining the research purpose and requesting permission to proceed. A total of two structured interviews were conducted, each lasting approximately 30–45 minutes. Responses were recorded through handwritten notes rather than audio recording. Interviews were conducted in Hausa, the vernacular language shared by respondents and researcher, and no translation was required.

5.5 Data Analysis Procedures

Likert-scale responses were tabulated and reported descriptively (as individual ratings or, where multiple respondents are available, as frequency distributions) rather than subjected to inferential statistical testing, given the small, purposive sample. Open-ended interview responses were analysed thematically, with themes organised around the study's core areas of interest: siting and orientation logic, spatial/courtyard organisation, material sourcing, thermal comfort perception, and continuity/change in practice. Coding of open-ended interview responses was conducted manually by the researcher, without the use of qualitative data analysis software, given the small, purposive sample.

5.6 Ethical Considerations

Interviews began with a verbal consent script informing respondents of the research purpose and their right to decline, consistent with basic informed-consent practice for community-based fieldwork. Clearance was obtained from the researcher's supervisor and the Head of Department prior to the commencement of data collection. On arrival at the study site, further approval was sought and obtained from the Hidi (traditional authority) before fieldwork proceeded, in addition to the individual verbal consent obtained from each respondent (Section 5.4.4).

5.7 Validity and Trustworthiness

Findings draw on two independent instruments architectural/spatial observation and structured interview allowing siting and material claims to be cross-checked against both what respondents reported and what was directly observed on site. This is a more limited form of triangulation than would be achieved with instrumented thermal data as a third source, which is acknowledged as a limitation below.

5.8 Methodological Limitations

This study's central limitation is the unavailability of thermal data-logging or temperature-measuring instrumentation during fieldwork. As a result, the study cannot report objective indoor temperature values, thermal lag durations, or instrument-verified energy performance figures for the sampled

structures; all thermal-performance statements in this paper are either occupant-reported perceptions or figures drawn from published literature on comparable construction systems, and the two should not be conflated. The study is further limited by its reliance on a small, purposive sample of respondents and sites, which restricts generalisability, and by the absence of a formal life-cycle assessment for the material comparisons discussed in Section 4.2. These limitations define the appropriate scope of this paper's conclusions: as a documented, perception-based foundation for future instrumented research, not as a substitute for it.

6. TECTONIC ADAPTATION FRAMEWORK FOR RESIDENTIAL HOUSING

Rather than replicating Sukur huts stylistically, this study extracts the underlying siting, spatial, and material principles documented above and proposes their translation into contemporary residential housing. The framework below is derived from the documented practices in Section 4, read alongside comparable strategies reported in recent literature (Akubue & Adesina, 2023; Ajayi, Daramola, & Ayodele, 2024; Santos, Ferreira, & Lanzinha, 2024); it is presented as an indicative design proposition rather than an instrument-verified performance specification.

Sukur Tectonic Logic (Documented)	Contemporary Residential Housing Translation
Thick stone/mud walls, sourced locally	Stabilised compressed earth blocks (CEB) or comparable low-embodied-energy walling; wall thickness to be established through future testing
Compound clustering (~2–4 m spacing), rated 'Frequently' beneficial for coolness	Cluster-based residential layout around shared courtyards, informed by courtyard-geometry literature (Akubue & Adesina, 2023)
Terraced hillside siting responding to natural constraint	Stepped massing responsive to site topography; zoning from public to private space
Entrance orientation rule: never face directly east	Orientation guidelines minimising direct low-angle morning solar penetration at entrances and primary openings
Shading rated 'Very effective' at blocking direct sun	Deep roof projections and shaded verandas, sized through future daylighting/shading analysis
Local material sourcing (grass, mud, stone)	Locally sourced or regionally produced low-embodied-energy materials, prioritised over imported cement-based systems

Table 1: Tectonic Adaptation Framework Documented Sukur Principles to Contemporary Residential Housing Translation

7. COMPARATIVE SUMMARY OF OBSERVED AND PERCEIVED PERFORMANCE INDICATORS

Table 2 below replaces the earlier draft's instrument-derived performance comparison with a summary that distinguishes what this study documented or respondents reported from what is drawn from published literature. No column in this table represents an instrument measurement taken by this study.

Indicator	Conventional Concrete Housing (literature-reported)	Sukur Vernacular Housing (this study)
Wall construction	Sandcrete block; higher embodied energy (Sapna & Anbalagan, 2023)	Stone/mud wall; lower embodied energy per literature comparison (not independently tested)

Indicator	Conventional Concrete Housing (literature-reported)	Sukur Vernacular Housing (this study)
Occupant-rated comfort, hottest part of day	Discomforting (Very hot)	'Moderately hot' (self-rated by documented respondent)
Perceived shading effectiveness	Not effective (1/5, self-rated)	'Very effective' (5/5, self-rated)
Perceived effect of compound clustering on coolness	Not applicable: typically, standalone plots	'Frequently' beneficial (4/5, self-rated)
Additional mechanical cooling reported	Common reliance on fans/AC (Ajayi, Daramola, & Ayodele, 2024)	Occasional fan uses only; no AC reported
Roofing	Zinc/corrugated sheet (standard)	Historically thatch; now transitioning to zinc (documented community change)

Table 2: Comparative Summary Conventional Concrete Housing (Literature) vs. Sukur Vernacular Housing (Documented in This Study)

8. DISCUSSION

The evidence gathered here points to environmental negotiation embedded in ordinary practice rather than formal engineering: siting is constrained by terrain, orientation is governed by an explicit rule about solar penetration, and material choice is inseparable from what the immediate landscape provides. Contemporary residential housing in Adamawa State often departs from these principles, adopting imported forms with limited orientation control and higher-embodied-energy materials, a pattern consistent with broader findings on underused passive design in Nigerian housing (Ajayi, Daramola, & Ayodele, 2024).

Three points are worth foregrounding. First, the low-embodied-energy profile generally associated with unfired earth and stone systems (Sapna & Anbalagan, 2023) aligns with what residents describe sourcing directly from the surrounding landscape, though this study did not independently verify embodied-energy values for the sampled structures. Second, the perceived cooling benefit of compound clustering reported here is consistent with courtyard-geometry literature linking clustering and airflow (Akubue & Adesina, 2023), even though this study measured perception rather than airflow directly. Third, the community's own distinction between what should be preserved (stone, mud walls) and what has already changed (roofing material) is a socially grounded starting point for a translation framework, and arguably more reliable than an externally imposed judgement about which vernacular elements are 'authentic' or worth retaining.

These findings should be read as consistent with, rather than confirmatory of, the wider literature on vernacular thermal performance (Santos, Ferreira, & Lanzinha, 2024; Kalu & Ogunnaike, 2025) consistency is the appropriate claim for a perception-based, small-sample case study; a stronger claim would require the instrumented monitoring this study was unable to conduct.

9. POLICY AND EDUCATIONAL IMPLICATIONS

The findings carry implications for architectural education and housing policy in Nigeria. Based on the documented and literature-supported evidence above, the following are proposed:

- Incorporate documentation-based case studies of vernacular settlements including community interviews, not only instrumented performance data into architectural curricula, so that graduates learn to engage with indigenous design knowledge as it is practised, not only as it is measured.
- Support future instrumented research at sites such as Sukur, prioritising basic thermal monitoring equipment, to allow the perception-based findings in this study to be tested against measured data.

- Promote low-embodied-energy walling systems such as compressed earth blocks in public and institutional housing policy, drawing on the growing recent evidence base for their sustainability credentials (Sapna & Anbalagan, 2023).
- Encourage climate-responsive design guidelines for Adamawa State residential developments that reflect locally documented practices such as entrance orientation rules rather than only generic passive-design guidance.

Sustainable development in northern Nigeria does not require imported paradigms; it can draw on environmental reasoning already embedded in places such as Sukur, provided that reasoning is documented accurately and its evidentiary basis is stated honestly.

10. CONCLUSION

This study has documented siting, orientation, clustering, material, and socio-spatial practices in Sukur vernacular housing through architectural observation and structured community interviews, in the absence of thermal monitoring instrumentation. Within these limits, the evidence indicates that Sukur's building practices embed deliberate, if informally reasoned, responses to climate an explicit rule against east-facing entrances, close compound clustering that residents frequently associate with coolness, highly rated shading, and locally sourced low-embodied-energy materials alongside an ongoing, community-led evolution in roofing and room configuration.

Rather than presenting definitive performance benchmarks, this study offers a documented, perception-based starting point and a set of testable propositions summarised in the tectonic adaptation framework (Table 1) for future research with instrumented thermal monitoring, a larger sample, and a full seasonal monitoring cycle. Architectural translation from vernacular to contemporary residential typologies remains a promising direction for Adamawa State; this paper's contribution is to ground that translation in what Sukur's own residents and builders report and practise, rather than in unverified figures.

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INDIGENOUS BUILDING MATERIALS IN MAKURDI,BENUE STATE, NIGERIA: AVAILABILITY AND IMPLICATIONS FOR SUSTAINABLE ARCHITECTURE

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Abstract
The building and construction sector accounts for approximately 32% of global energy use and 34% of carbon dioxide emissions (UNEP & GlobalABC, 2025), pressures intensified in Nigeria by continued dependence on energy-intensive imported materials despite abundant laterite, earth, timber, bamboo and thatch. This paper investigates the availability and architectural potential of these five indigenous materials in Makurdi, Benue State, combining a review of 2021-2026 literature with a structured questionnaire survey of 100 construction professionals. Results confirm indigenous materials -- particularly laterite and earth -- are widely available and environmentally advantageous, but that adoption is constrained less by technical unsuitability than by negative public perception, limited professional knowledge and an absence of clear standards. The paper concludes that testing, standardisation, training and detailing can translate this latent potential into confident specification, offering a pathway toward sustainable, locally grounded architecture in Makurdi and comparable rapidly urbanising contexts.
Keywords: Indigenous building materials; Sustainable architecture; Makurdi; Laterite; Earth construction; Low-carbon architecture.

1. INTRODUCTION

Sustainable architecture has increasingly moved beyond operational energy efficiency to address the environmental impacts of material production, transport, maintenance and disposal. United Nations Environment Programme.reports the buildings and construction sector accounts for roughly 32% of global energy consumption and 34% of carbon dioxide emissions, with cement and steel driving much of this impact (UNEP & GlobalABC, 2025); an "Avoid-Shift-Improve" framework for material decarbonisation has been proposed in response (UNEP, 2023). Nigeria possesses substantial natural resources and long-standing traditions of using earth, laterite, timber, bamboo and grasses in construction, offering a locally appropriate alternative to imported, energy-intensive materials. The critical question is not whether indigenous materials should replace conventional ones, but how they can be selectively integrated with contemporary technology. Adetoro and Gambo (2025), studying professional engagement with mud construction, found growing awareness of its ecological and cultural value alongside persistent durability concerns, regulatory uncertainty and outdated perceptions -- suggesting the barrier is increasingly one of implementation rather than environmental potential. This issue is particularly relevant to Makurdi, capital of Benue State, which lies within Nigeria's Guinea Savannah and experiences a warm climate (approximately 27-28°C) with substantial seasonal rainfall (around 1,290 mm annually), making solar control, ventilation and moisture management central architectural considerations. Indigenous materials may support climate-responsive design through thermal mass, natural insulation and low-energy processing, but their performance depends strongly on detailing, treatment and environmental exposure. This study combines a literature review with a primary questionnaire survey of construction professionals, examining laterite, earth/adobe, bamboo, timber and thatch with attention to their availability, environmental implications, climatic relevance and barriers to adoption in Makurdi.

2. LITERATURE REVIEW

2.1 Sustainability and the material question

Life-cycle environmental impact, not only operational performance, increasingly shapes material selection. UNEP & GlobalABC (2025) confirm the sector's 32%/34% energy and emissions share, with cement and steel alone responsible for close to a fifth of building-related emissions; UNEP (2023) frames embodied carbon reduction around avoiding unnecessary construction, shifting toward low-carbon and bio-based materials, and improving conventional material efficiency. Indigenous materials sit primarily within the "shift" category: they do not eliminate the need for conventional materials, but offer a lower-carbon pathway where their performance is adequate.

2.2 Indigenous materials in the Nigerian context

Nigeria's construction sector remains dependent on imported materials despite extensive laterite and clay deposits, established timber and bamboo resources, and a long thatch-roofing tradition. Laterised concrete studies confirm laterite can substitute conventional fine aggregate without disproportionate strength loss when appropriately graded (Ukpata *et al*., 2024). Adetoro and Gambo (2025) found architects increasingly aware of mud construction's value but constrained by durability concerns and weak detailing innovation. Bamboo reviews report favourable strength-to-weight characteristics and rapid renewability but note the absence of national grading standards (Onyechere et al., 2023); timber assessments similarly favour it on embodied-carbon grounds while flagging decay and inconsistent preservative treatment (Abimaje and Baba, 2014). Thatch remains the least documented of the five materials in the technical literature.

Table 1: Summary of Reviewed Indigenous Building Materials

Material	Availability	Key Barrier	Key Source
Laterite	Abundant, informally quarried	Variable grading	Ukpata *et al*. (2024)
Earth/Adobe	Abundant clay-rich soils	Durability perception	Adetoro and Gambo (2025)
Bamboo	Present in riverine areas	No grading standards	Onyechere *et al*. (2023)
Timber	Moderate, costly	Decay/treatment gaps	Abimaje and Baba (2014)
Thatch	Locally available	Scarce documentation	Vernacular surveys

2.3 Climatic context of Makurdi

Makurdi's tropical wet-and-dry climate (rainy season April-October) places a premium on moisture management. Field research at Agan found traditional buildings perceived as more thermally comfortable than semi-modern alternatives despite measuring marginally warmer and more humid, attributed to greater occupant tolerance for humidity than temperature (Tyubee, *et al*, 2020). More recent work identifies capillarity-induced rising damp -- driven by high groundwater, seasonal rainfall and absent damp-proof courses - as a measurable driver of wall moisture and cooling energy demand (Gwaza, 2026). Together these studies suggest Makurdi's climate is broadly compatible with earthen materials, but in-service performance is highly sensitive to detailing at the wall base, eaves and roof-wall junction.

3. METHODOLOGY

This study combines a narrative literature review (2021-2026; Google Scholar, ResearchGate, FUTMinna repository) with field observation of construction practice in Makurdi, and a structured questionnaire survey of 197 construction professionals purposively sampled for prior experience with indigenous materials (confirmed at intake, 100% response). Five materials were selected -- laterite, earth/adobe, bamboo, timber, thatch -- spanning the principal structural and enclosure functions of a building envelope. The questionnaire covered nine thematic sections (respondent profile; availability and utilisation; environmental and low-carbon performance; climatic suitability; technical performance

criteria; socio-economic considerations; challenges; improvement strategies; architectural integration), using five-point Likert-type scales analysed via weighted mean ranking. Internal consistency across the seven multi-item scales, assessed via Cronbach's alpha, ranged from 0.90 to 0.96, comfortably exceeding the 0.70 acceptability threshold.

4. STUDY AREA

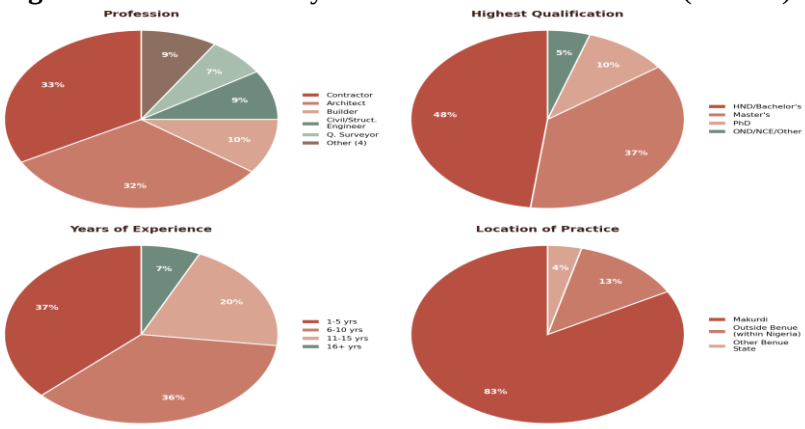
The study is situated in Makurdi, capital of Benue State, in Nigeria's North Central geopolitical zone at approximately 7°44'N, 8°32'E, on the banks of the River Benue. The town lies within the Guinea Savannah zone, with average temperatures of 27-29°C and substantial seasonal rainfall. Surrounding soils are predominantly lateritic and clay-rich, supporting an established tradition of informal laterite quarrying and local brick production, though rapid urban growth is placing new pressure on this material base.

5. RESULTS AND DISCUSSION

5.1 Respondent Profile

Contractors (33%) and architects (32%) formed the largest professional groups; 85% held a Bachelor's degree or higher, and 73% had ten years' experience or less. The large majority (83%) practised primarily in Makurdi. All respondents confirmed prior experience with indigenous materials.

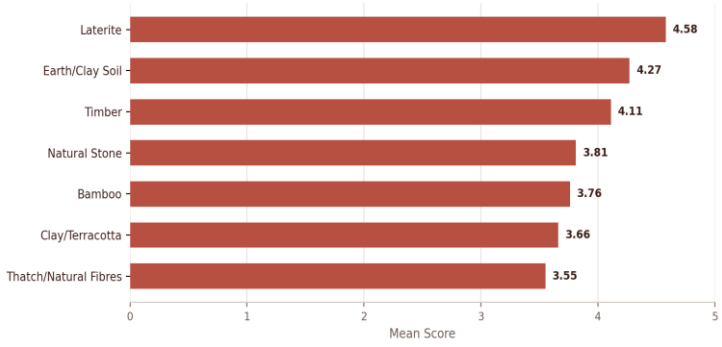
Figure 1: Profile of Surveyed Construction Professionals (n = 100)



5.2 Material Availability and Potential

Laterite was rated the most available material (M = 4.58), followed by earth/clay (4.27) and timber (4.11); thatch was lowest (3.55). This ranking closely tracked perceived architectural potential: 88% selected laterite/earth and 83% selected timber, confirming laterite as the most viable entry point for material integration in Makurdi.

Figure 2: Perceived Availability of Indigenous Materials



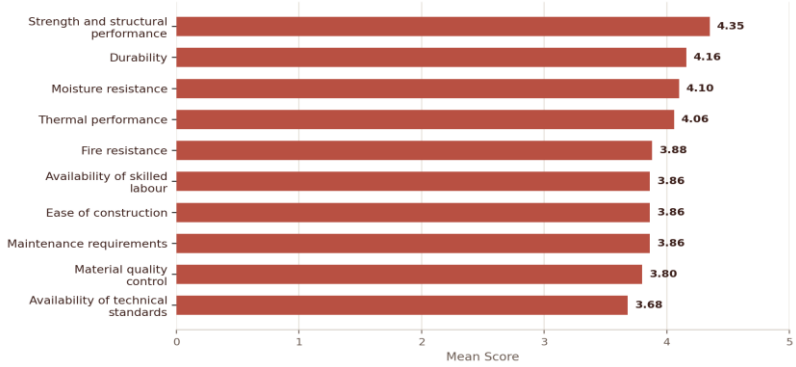
5.3 Environmental and Climatic Performance

Respondents strongly endorsed the environmental case for local sourcing, rating reduced transportation emissions highest (M = 4.61) and reduced industrial processing second (4.27), though ratings for waste reduction and life-cycle assessment were more moderate -- suggesting acceptance of transport benefits but caution about broader circularity claims. Climatic suitability for Makurdi's hot conditions was rated highly overall (4.25), while protection against moisture and humidity scored lowest among specific attributes (3.62), identifying rainfall management, not heat, as the more demanding technical concern -- consistent with the rising-damp findings of Gwaza (2026).

5.4 Technical Performance Priorities

Strength and structural performance was the top-rated technical criterion (M = 4.35), followed by durability (4.16) and moisture resistance (4.10); availability of technical standards ranked lowest (3.68) -- a gap suggesting practitioners currently rely on direct experience rather than codified criteria.

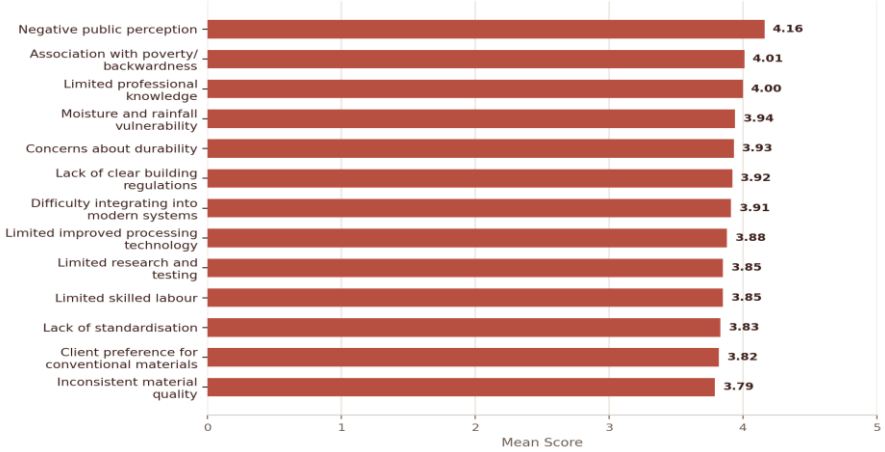
Figure 3: Technical Performance Criteria (Ranked by Mean Score)



5.5 Socio-Economic Considerations and Challenges

Strengthening cultural identity was the highest-rated socio-economic benefit (M = 4.44), while suitability for luxury architecture scored lowest (3.80). Negative public perception was the top-ranked barrier to adoption (M = 4.16), ahead of every technical concern including moisture vulnerability (3.94) and durability (3.93) -- confirming that the principal obstacle in Makurdi is social and reputational rather than technical.

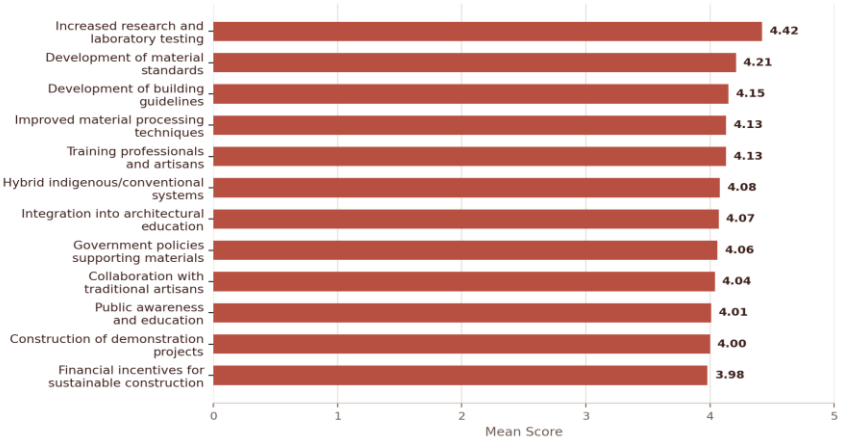
Figure 4: Challenges Constraining Adoption of Indigenous Materials (Ranked by Mean Score)



5.6 Improvement Strategies and Architectural Integration

Increased research and laboratory testing was rated the most important improvement strategy (M = 4.42), followed by material standards (4.21) and building guidelines (4.15) -- directly mirroring the top-ranked challenges. External wall construction was identified as offering the greatest scope for material integration (M = 4.23), followed by internal wall finishes (4.07).

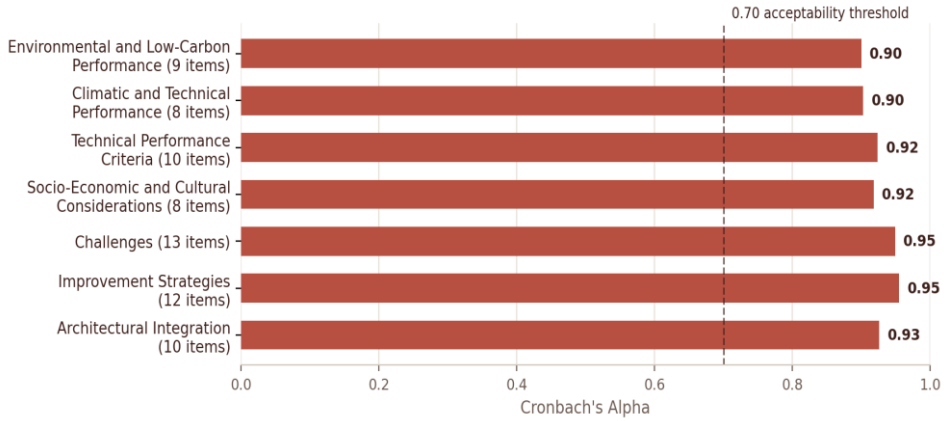
Figure 5: Strategies for Improving Utilisation (Ranked by Mean Score)



5.7 Instrument Reliability

All seven multi-item rating scales returned Cronbach's alpha between 0.90 and 0.96, indicating excellent internal consistency and supporting confidence in the ranked findings above.

Figure 6: Reliability of Multi-Item Rating Scales



6. SYNTHESIS

Literature and survey evidence converge on a single conclusion: technical and environmental potential is not the limiting factor on indigenous material use in Makurdi. Laterite and earth are already embedded in the town's informal construction economy and rated highest for both availability and potential, yet remain marginal in formally designed buildings -- a gap literature attributes to durability perception and regulatory uncertainty (Adetoro and Gambo, 2025) and the survey confirms directly: negative perception outranks every technical concern. Bamboo and timber are similarly constrained less by performance than by the absence of national treatment and grading standards (Onyechere et al., 2023; Abimaje & Baba, 2014), mirrored in the survey's low priority for technical standards relative to structural performance. The more productive intervention is therefore not a binary choice between indigenous and conventional materials, but development of locally calibrated detailing guidance, damp-proofing and finish standards -- alongside the testing, standardisation and training both bodies of evidence identify as priorities.

7. LIMITATIONS

The survey relies on self-reported professional perception rather than laboratory material testing. The sample is concentrated among professionals practising in Makurdi (83%), limiting generalisability elsewhere in Nigeria, and the cross-sectional design captures perception at a single point in time. The study is confined to five focal materials and does not address natural stone, which emerged as relevant during the survey.

8. CONCLUSION

This study confirms that laterite, earth, timber, bamboo and thatch are all perceived as available and architecturally promising in Makurdi, with laterite standing out as both the most available and most promising material. The principal barrier to wider adoption is not technical unsuitability but negative public perception, limited professional knowledge and an absence of clear standards. Encouragingly, the strategies professionals rate most highly -- research and testing, standardisation, training -- map directly onto these barriers, suggesting a practical and shared agenda for improvement. Realising this potential depends less on demonstrating environmental credentials, already broadly accepted, than on the applied work of testing, detailing and standardising that can translate acceptance into confident specification -- offering a pathway toward architecture that is low-carbon, climate-responsive and rooted in the material culture of its region.

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SCREENING AND ISOLATION OF METHIONINE-PRODUCING BACTERIA AND THEIR FERMENTATION OF ENZYMATICALLY HYDROLYZED AGRICULTURAL WASTES

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Abstract
Methionine is an essential sulphur-containing amino acid widely utilized in the food, feed, and pharmaceutical industries. This study isolated a novel methionine-producing bacterium and evaluated enzymatically hydrolyzed agrowastes as cost-effective carbon sources for its production. Following screening on a minimal salt medium, the highest-yielding isolate was characterized as a Gram-positive strain exhibiting positive catalase, citrate, and urease activities. Six alkaline-pretreated agricultural wastes including rice bran, maize cob, melon husk, groundnut shell, plantain trunk, and sugarcane bagasse were hydrolyzed using cellulase derived from *Aspergillus niger*. Analysis via the dinitrosalicylic acid method revealed reducing sugar concentrations ranging from 0.167 mg/mL for sugarcane bagasse to a peak of 0.509 mg/mL for rice bran. Subsequent sodium nitroprusside colorimetric assays confirmed that methionine production aligned with these sugar levels. Rice bran hydrolysate yielded the highest methionine concentration at 1.54 mg/mL, significantly outperforming other substrates like groundnut shell (1.28 mg/mL) and sugarcane bagasse (0.12 mg/mL). These findings highlight enzymatically hydrolyzed rice bran as a highly viable substrate for microbial methionine synthesis, emphasizing the broader potential of agricultural waste valorization for sustainable amino acid production.
Keywords: Methionine biosynthesis, agricultural waste valorization, enzymatic hydrolysis, bacterial fermentation, reducing sugars.

IN SILICO DRUG DISCOVERY OF BANGLADESHI MEDICINAL PLANT-DERIVED PHYTOCHEMICALS TARGETING THE MEK1/ERK2 SIGNALING PATHWAY IN LUNG CANCER

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Abstract
Lung cancer remains one of the most prevalent and deadly malignancies worldwide, with increasing incidence and mortality despite advances in therapeutic strategies. Dysregulation of the mitogen-activated protein kinase (MAPK) signaling pathway, particularly the MEK1/ERK2 cascade, plays a pivotal role in cancer cell proliferation, survival, metastasis, and therapeutic resistance. Therefore, targeting MEK1 and ERK2 represents a promising approach for the discovery of novel anticancer agents. This study aimed to identify potential phytochemical-based MEK1/ERK2-targeting candidates from Bangladeshi medicinal plant-associated phytochemical resources through an integrated in silico drug discovery approach. Bioactive phytochemicals were screened against MEK1 (PDB ID: 7B7R) and ERK2 (PDB ID: 6SLG) using molecular docking analysis. Several phytochemicals exhibited strong binding affinities and favorable interactions with both target proteins. Among the identified candidates, Baicalin (CID:64982) showed the strongest binding affinity toward MEK1 (-10.2 kcal/mol), whereas Nimolinone (CID:56841069) demonstrated the highest affinity against ERK2 (-10.7 kcal/mol). Furthermore, 7-Deacetoxy-7-oxogedunin (CID:71300386), Oroxindin (CID:3084961), and Nimolicinol (CID:184937) exhibited promising dual-target binding potential. ADMET profiling was performed to evaluate the drug-likeness, pharmacokinetic properties, and toxicity characteristics of the selected compounds, including physicochemical properties, gastrointestinal absorption, cytochrome P450 interactions, Lipinski's rule of five, and toxicity parameters. The selected phytochemicals demonstrated acceptable drug-likeness characteristics, favorable pharmacokinetic profiles, low predicted hepatotoxicity risk, and minimal hERG inhibition potential. Collectively, Baicalin, Nimolinone, 7-Deacetoxy-7-oxogedunin, Oroxindin, and Nimolicinol were identified as potential MEK1/ERK2-targeting lead molecules, warranting further validation through molecular dynamics simulation and experimental studies. This study highlights the therapeutic potential of medicinal plant-derived phytochemicals and provides a computational framework for the discovery of novel MAPK pathway-targeted therapeutic candidates against lung cancer.
Keywords: Lung cancer; MEK1; ERK2; MAPK pathway; Phytochemicals; Drug discovery.

EXPLORATION OF SOCIOLOGICAL AND URBAN DETERMINANTS OF HAPPINESS AMONG MIDDLE-AGED URBAN ADULTS USING GROUNDED THEORY APPROACH

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Abstract
This grounded theory study explored the Sociological and Urban determinants of happiness among middle-aged urban adults in Pakistan using grounded theory approach. The research addresses a significant gap in existing literature in which the middle-aged population is widely overlooked. The data was collected using in-depth semi-structured interviews technique. The participants included 20 adults aged 35–60 years from various professions. Data were analyzed using Strauss and Corbin's grounded theory procedures, including line-by-line open coding, axial coding and selective coding. The analysis identified following key determinants of happiness: Social factors, Personal attributes and Urban determinants. Social determinants included judicious relationships, work-life balance, rest and leisure, family happiness, quality time with family and friends, and meditation or religiosity. Personal attributes included hope, nurturance, appreciation of life, contentment, forgiveness and avoidance of destructive emotions. Urban life was experienced ambivalently: it enhanced happiness through opportunities, facilities, autonomy from family interference and historical attachment, but diminished happiness through high living costs, individualism, environmental degradation, reduced simplicity and limited social life. The study has wide implications in terms of understanding how various sociological and urban factors could enhance or diminish the happiness of individuals. *Keywords*: Social determinants; Urban Determinants; Personal Resources; middle-aged adults; urban life; Happiness; wellbeing

SEMI-ANALYTICAL INVESTIGATION OF A NON-LINEAR INITIAL VALUE PROBLEM IN A CANCER MODEL

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Abstract
Cancer is a serious disease characterized by the uncontrolled growth and spread of abnormal cells in the body. It can develop in almost any organ or tissue and may spread to other parts of the body if not detected and treated early. The Homotopy Pertubation Method (HPM) is employed to address the system of non-linear differential equations and generate a semi-analytical solution for the Cancer disease Protected-Susceptible-Infected-Treated (PSITPS) model. These Methods results were compared with the MATLAB numerical simulation. There is a good agreement between the numerical simulation and the approximate analytical results. In addition, each parameter was varied to examine its impact on the behaviour of individuals in the model. The findings of this study provide useful guidance for researchers on the use of semi-analytical methods in infectious disease epidemiological modelling.
Keywords: Epidemic model, Cancer, non-linear initial value problem, Homotopy Pertubation method (HPM), numerical simulation.

HISTOPATHOLOGICAL AND BEHAVIOURAL RECOVERY OF ZEBRAFISH (DANIO RERIO) FOLLOWING ADSORPTION-BASED DETOXIFICATION OF AURAMINE O DYE: A SUSTAINABLE APPROACH TO ENVIRONMENTAL HEALTH

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Abstract
The discharge of industrial textile effluents containing persistent synthetic dyes like Auramine O presents a critical threat to aquatic biodiversity and global environmental health. These aromatic compounds resist conventional treatment protocols and accumulate in the food chain, posing significant carcinogenic risks to both fauna and humans. A substantial research gap exists in identifying low-cost, sustainable adsorbents that can effectively eliminate these pollutants while restoring the physiological health of aquatic organisms. This study addresses this challenge by investigating the remediation potential of activated carbon (AC) synthesized from *Phaseolus lunatus*. The primary objective was to identify the optimal AC dosage (0.1–1.0 g/L) required to detoxify a 0.025ppt Auramine O solution, using adult zebrafish (*Danio rerio*) as a high-homology toxicological bio-indicator. Results revealed that untreated dye solutions were acutely lethal, resulting in 100% zebrafish mortality within 72 hours, accompanied by severe behavioral distress and histopathological damage, including gill lamellae fusion, severe intestinal inflation, and retinal layer detachment. Remarkably, an optimal AC dosage of 1.0 g/L achieved 98.9% decolorization, restoring 100% survival and total normalization of physical activities. These findings confirms that *Phaseolus lunatus*-derived AC effectively sequesters toxic molecules, preventing their absorption through sensitive respiratory and digestive membranes. Our study will focus on long-term chronic toxicity assessments (168h+), analyzing molecular oxidative stress markers, and evaluating treated water for agricultural irrigation to support circular economy initiatives in industrial regions

Keywords: Auramine O, *Phaseolus lunatus*, Zebrafish, Histopathology, Sustainable Remediation

MACHINE LEARNING-ASSISTED INTEGRATION OF ELECTRICAL RESISTIVITY TOMOGRAPHY, SEISMIC REFRACTION TOMOGRAPHY, AND BOREHOLE DATA FOR ENGINEERING SITE CHARACTERIZATION IN TROPICAL WEATHERED TERRAIN

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ABSTRACT
Reliable subsurface characterization is fundamental to engineering site investigations, particularly in tropical weathered terrains where lithological heterogeneity and weathering processes introduce significant uncertainty into geophysical interpretation. This study presents a machine learning-assisted framework integrating Electrical Resistivity Tomography (ERT), Seismic Refraction Tomography (SRT), and borehole-derived Standard Penetration Test (SPT-N) data for engineering geological characterization in Kabota-Tawau, Sabah, Malaysia. A dataset comprising 491 spatially collocated electrical resistivity (ER) and seismic P-wave velocity (Vp) observations was analysed using exploratory statistical analysis, Principal Component Analysis (PCA), K-means clustering, Self-Organizing Maps (SOM), and regression modelling. PCA revealed that the first principal component explained 94.75% of the total variance, indicating that ER and Vp are predominantly controlled by common geological factors. Comparative clustering identified four engineering geological domains representing progressive transitions from highly weathered materials to competent rock. Although statistical validation indices favoured a two-cluster solution, the four-cluster model provided the most meaningful engineering geological interpretation and was independently validated using SOM and borehole-derived SPT-N data. Regression analysis showed that ER correlated more strongly with SPT-N than Vp, while Vp provided complementary information on subsurface elastic behaviour. The proposed framework reduces interpretation uncertainty and provides a practical, transferable methodology for engineering site characterization and infrastructure planning in tropical weathered terrains.

Keywords: Electrical Resistivity Tomography; Seismic Refraction Tomography; Engineering Site Characterization; Machine Learning; Tropical Weathered Terrain.

ENVIRONMENTAL GOVERNANCE OF REAL ESTATE AND URBAN DEVELOPMENT: A COMPARATIVE ANALYSIS OF INDIA, SINGAPORE AND THE UNITED KINGDOM

Atharva Sanjay NAIK

Abstract

Environmental governance in real estate and urban development has become a critical policy imperative amid climate change, resource scarcity, and rapid urbanization. This paper comparatively examines the environmental regulatory frameworks shaping real estate and urban development in India, Singapore, and the United Kingdom, three jurisdictions with differing governance capacities and sustainability priorities.

India's environmental governance operates through the Environment (Protection) Act, 1986, Environmental Impact Assessment (EIA) Notification, and green building certifications (GRIHA, IGBC), yet faces challenges including fragmented enforcement, weak monitoring, and tension between rapid urbanization and ecological safeguards. Singapore exemplifies proactive, state-led environmental planning through its Green Building Masterplan, BCA Green Mark certification, and integrated land-use planning under the URA, achieving high compliance through centralized governance and technological monitoring. The United Kingdom demonstrates a mature regulatory approach anchored in planning law, the Climate Change Act 2008, Building Regulations Part L, and emerging Biodiversity Net Gain requirements under the Environment Act 2021, reflecting a shift toward legally binding net-zero commitments in the built environment.

The study identifies convergent trends green certification systems, energy efficiency mandates, and climate-responsive planning alongside divergences in enforcement rigor, institutional coordination, and market incentivization. India's decentralized enforcement contrasts with Singapore's centralized precision and the UK's litigation-reinforced compliance culture.

The paper concludes that effective environmental governance requires harmonizing legal mandates, institutional capacity, and market-based incentives, suggesting that India could benefit from Singapore's integrated planning models and the UK's statutory climate accountability mechanisms.

Keywords: Environmental Governance, Sustainable Development, Real Estate, Urban Planning, Green Building, EIA, Climate Change Act, BCA Green Mark, India, Singapore, United Kingdom, Comparative Law

COMPOST BASED ELECTROCHEMICAL ENERGY STORAGE

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Abstract
The increasing demand for sustainable and low-cost energy-storage technologies has encouraged the exploration of biomass-Based materials as alternative functional materials. Compost, generated from plant and animal waste, represents an abundant and environmentally friendly resource that can be valorised for electrochemical applications. The present research focuses on the development and investigation of compost-based electrochemical energy-storage using a symmetric two-electrode configuration. Different compost samples with varying C:N ratios are investigated using Graphite, Copper and Inconel as current collectors. The influence of different electrolytes, including DI water, KCl, KNO_3 and KOH, at different concentrations is systematically studied to understand their effect on charge-storage behaviour.The electrochemical performance of the developed devices is evaluated using Cyclic Voltammetry (CV), Galvanostatic Charge–Discharge (GCD), and Electrochemical Impedance Spectroscopy (EIS). The charge-storage mechanism is further examined by analysing the capacitive and Faradaic contributions, while impedance analysis is used to evaluate internal resistance, charge-transfer processes and ion-diffusion behaviour.

VACCINATION AND ECONOMIC GROWTH IN NIGERIA

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ABSTRACT
The health of a population is important from a social and economic perspective as healthy individuals contribute to economic growth. Vaccination has the potential to reduce infant mortality and contribute substantially to improving population health and thereby economic growth. Healthy children are more able to participate in education, thus preparing them to become healthy and productive adults. Vaccination programmes can also prevent infectious diseases in adolescents, thus allowing them to continue their development towards a healthy adulthood. Therefore, assessment of the impact of vaccines and vaccination needs to consider not just the direct impact on health and healthcare but also the wider impact on economic growth. This study attempts to investigate the relationship between vaccination and economic growth and development. however, there is scanty of empirical literature on the impact of vaccination on economic growth this study employed ordinary square (OLS) estimation technique to examine the impact of vaccination and immunization on economic growth and found that vaccination have negative but insignificant impact on economic growth in Nigeria while immunization against infectious diseases have positive but not significant impact on economic growth.
Keywords: Vaccination, infant mortality, productivity, economic growth, investment

COMPOST-DERIVED HUMIC SUBSTANCES AS GREEN PRECURSORS FOR BIOMEDICAL NANOPARTICLE SYNTHESIS AND NANOMEDICINE APPLICATIONS

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Abstract
The valorization of compost-derived organic matter into high-value biomedical nanomaterials represents an emerging strategy at the interface of circular bioeconomy and nanomedicine. Composting promotes the progressive transformation of biodegradable organic matter into chemically complex humified fractions, particularly humic acids (HA), fulvic acids (FA), and humin. These substances contain abundant carboxyl, phenolic, hydroxyl, quinone, and carbonyl functionalities capable of complexing metal ions, transferring electrons, and interacting with biological macromolecules. Following alkaline extraction and physicochemical fractionation of mature compost, these functional groups can be exploited for the green synthesis and surface functionalization of nanoparticles.
Compost-derived humic substances may act simultaneously as reducing, nucleating, stabilizing, and capping agents, enabling the formation of metallic or metal-oxide nanoparticles with controlled colloidal stability and biologically active surfaces. Such nanostructures have potential applications in antimicrobial therapy, drug delivery, cancer nanomedicine, wound management, bioimaging, and controlled release systems. The redox-active aromatic domains of humic molecules may further influence nanoparticle formation, reactive oxygen species generation, cellular interactions, and therapeutic activity. Importantly, the biological performance of these materials is strongly dependent on compost maturity, feedstock composition, extraction conditions, molecular-weight distribution, elemental composition, and the abundance of oxygenated functional groups.

Comprehensive characterization using FTIR, UV–Vis spectroscopy, fluorescence spectroscopy, elemental analysis, XPS, XRD, DLS, zeta potential, and electron microscopy is therefore required to establish structure–property relationships. This approach transforms compost-derived humic matter from a low-value organic fraction into a functional platform for sustainable nanomedicine, while simultaneously contributing to waste valorization and circular resource recovery.

Keywords: Humic acids; Fulvic acids; Green nanotechnology; Nanoparticle synthesis; Biomedical nanoparticles; Nanomedicine; Sustainable waste valorization.

ANTIMICROBIAL RESISTANCE AT THE HUMAN–ANIMAL–ENVIRONMENT INTERFACE: EMERGING THREATS, TRANSMISSION PATHWAYS AND ONE HEALTH CONTROL STRATEGIES

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ABSTRACT

Antimicrobial resistance (AMR) is an escalating global health threat that extends beyond human medicine and represents a complex One Health challenge at the interface of human, animal and environmental health. The inappropriate and excessive use of antimicrobial agents in human healthcare, livestock production, aquaculture and other food-producing systems creates selective pressure that promotes the emergence and dissemination of resistant microorganisms and antimicrobial resistance genes. These resistant organisms and genetic determinants can circulate across interconnected sectors through direct contact, food, water, wastewater, animal waste and contaminated environments, facilitating the persistence and spread of AMR.

This review examines AMR from a One Health perspective, focusing on emerging threats, transmission pathways and integrated control strategies. Particular attention is given to antimicrobial use across human and animal health, environmental reservoirs of resistance, horizontal gene transfer, food-chain transmission, and the role of wastewater and agricultural environments in the dissemination of resistant microorganisms. The review also highlights major challenges to effective AMR control, including inappropriate antimicrobial use, inadequate infection prevention and control, limited laboratory capacity, fragmented surveillance systems, weak regulatory frameworks and insufficient coordination between sectors, particularly in low- and middle-income countries. Current control strategies, including antimicrobial stewardship, integrated One Health surveillance, responsible antimicrobial use in agriculture and animal health, vaccination, infection prevention and control, environmental management, genomic surveillance, research and development, and public health education, are discussed. The review emphasizes that effective AMR control requires coordinated, multisectoral action across human, animal, food and environmental health systems. A One Health approach is therefore essential for understanding and interrupting the transmission of AMR and preserving the effectiveness of antimicrobial agents for future generations.

POLLUTION INDICES AND HEALTH RISK ASSESSMENT OF HEAVY METALS IN AN URBAN PLAYGROUND SOIL FROM KATSINA STATE, NORTH-WESTERN NIGERIA

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ABSTRACT
The pollution indices and health risk to population from exposure to heavy metals in an urban playground were assessed in the present study. The evaluation of heavy metals was carried out using Atomic Absorption Spectrophotometry. The heavy metals soil pollution indices and possible health risks to the population were computed based on the Geoaccumulation index (*I*geo), enrichment factor (EF), contamination factor (CF), pollution load index (PLI), potential ecological risk index (PERI) and the United States environmental protection agency (USEPA) Hazard Quotient (HQ) and Hazard Index (HI)) to assess the possible non-carcinogenic effect and the Incremental Lifetime Cancer Risk (ILCR) for the cancer risks respectively. The results had revealed that all the evaluated heavy metals were within safe limits. The I-geo values revealed that the soil sample was unpolluted with these heavy metals. The result of the heavy metal EF of the soil sample also showed varying degree of enrichment; Fe and Mn (Deficiency to minimal Enrichment); Zn (Moderate enrichment); Ni (Significant enrichment); Cr (Extremely high enrichment). The result of the contamination factor has indicated that the soil sample in the study has low contamination by the heavy metals. The result of pollution load index was less than 1. With the potential ecological risk index (PERI) values presenting low ecological risks. The calculated non-cancer risk indices in both the children and adults' population for the heavy metals Ni and Zn were below 1, with the exception of the heavy metals Mn, Fe and Cr whose values were above 1. The computed pollution indices have shown that the soil sample have low contamination, while the results for the health risk evaluation have indicated a possible contribution of exposure to the soil sample to heightened risks for cancer cases in the population.
Keywords: Soil, Environment, Heavy metals, Katsina, pollution, Cancer, Health.

ASSESSING AWARENESS,SELF-REPORTING PRACTICE AND BARRIERS TO INCIDENT REPORTING :ACROSS-SECTIONAL STUDY AMONG NURSES

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Abstract

Background: Incident reporting is a core patient-safety function that supports organizational learning by capturing errors, adverse events, and system weaknesses. Although reporting systems may be available in accredited hospitals, nurses' reporting behavior can remain suboptimal when social, legal, and confidentiality concerns persist.

Aim: This study examined nurses' awareness of incident reporting practices and perceived barriers to incident reporting at Al Quwayiyah General Hospital, Kingdom of Saudi Arabia (2024).

Methods: A cross-sectional case study design was used in a fully accredited (100%) governmental hospital. A total of 223 nurses participated. Data covered nurses' awareness and access to the reporting system, reporting practice (including recent reporting), perceptions across 11 incident scenarios (occurrence/recognition, actual reporting, and perceived obligation to report), and perceived barriers. Descriptive statistics, correlation testing, and group comparisons were applied to examine relationships between awareness, barriers, and reporting practice and to explore differences across demographic variables.

Results: Most nurses reported the existence of an incident reporting system (88.8%) and knew how to access reporting forms (81.2%); 69.1% had ever completed an incident form, yet only 38.1% had submitted a report in the last month. The overall awareness/practice score averaged 3.58 ± 1.219. Scenario-based responses indicated high recognition of incidents (e.g., "Always" recognition frequently ~65%–74% for key events), while consistent "Always" actual reporting was lower (e.g., pressure sores 48.0%, falls 45.3%, DVT 40.8%), despite higher endorsement that incidents should be reported (~61%–68% "Always"). The mean reporting practice score was 3.010 ± 0.3925, and the mean barrier score was 2.876 ± 0.6092. The highest perceived barriers were lack of coworker support (3.11 ± 1.193), worry about litigation (3.08 ± 1.281), and concerns about who could access disclosed information (3.06 ± 1.167). Awareness correlated positively with reporting practice ($r = 0.326$; $p < 0.001$), while barriers correlated negatively with reporting practice ($r = -0.424$; $p < 0.001$); awareness was not correlated with barriers ($r = 0.012$; $p = 0.854$). Reporting practice differed by gender ($p = 0.036$) but not by education; experience and age were not significantly associated with the main scores.

Conclusion: High system awareness and access were observed, but a clear recognition–reporting gap persisted. Reporting practice was strengthened by awareness and constrained by perceived barriers, particularly coworker support, litigation concerns, and confidentiality-related worries. Targeted strategies that reinforce supportive, confidential, and non-punitive reporting environments were indicated to improve consistent reporting behavior.

Keywords: Incident reporting; Nurses; Patient safety; Reporting barriers; Safety culture; Accredited hospital; Saudi Arabia.

ASSESSMENT OF SUGARCANE BAGASSE DERIVED BIOASH FOR THE REMOVAL OF METHYL VIOLET AND CRYSTAL VIOLET DYES

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Abstract
The rising number of synthetic dyes in the wastewater produced by industries calls for an efficient yet easy approach to deal with this issue. In this study, the potential of sugarcane bagasse bioash was investigated as a new adsorbent for the removal of Methyl Violet and Crystal Violet from aqueous solutions. The adsorption capability of both dyes was examined with respect to the experimental parameters such as pH, contact time, temperature, and dosage of the adsorbent. A 50 ppm dye solution was used in different doses of bioash, and the difference in the concentration of dye was measured after the process. The adsorption capability of the dyes was significantly affected by the experimental parameters, where an increased contact time resulted in higher adsorption of the dyes. Methyl Violet has shown a maximum removal rate of 50.00% within 90 min especially at higher pH levels at 45°C. On the other hand, the maximum removal rate of Crystal Violet was 40.74% at pH 7 after 90 min at 45°C. The different removal rates of the two dyes have shown that the interaction of the dyes with the bioash surface is affected by the physicochemical properties of the dyes. Overall, the findings highlight the potential of sugarcane bagasse bioash as a readily available and economical adsorbent for reducing Methyl Violet and Crystal Violet contamination in aqueous systems, providing a value-added application for an agricultural by-product.
Keywords: Sugarcane bagasse bioash; Dye removal; Methyl Violet; Crystal Violet; Adsorption; Wastewater treatment; Agricultural waste; Sustainable adsorbent.

Introduction

Water is a fundamental natural resource sustaining living things and multiple uses in domestic, agricultural, and industrial sectors. But industrialization and increased human activity lead to contamination of water sources with wastewater without proper treatment. Industrial effluent may contain complex organic and inorganic pollutants. Synthetic dyes are the main types of such pollutants. Dyes are used in textile, paper, leather, printing, plastics and other industries. Release of dye-containing effluents into water bodies leads to its contamination and colouring. Persistent and stable chemical properties of dyes make the treatment of dye-containing water a serious environmental problem (Piaskowski et al., 2018).

The use of dyes in wastewater is not only connected with the high colouring but also can be dangerous because some dyes and their decomposition products can produce toxic effects. Water with the high concentration of dyes can decrease light transmission in water bodies and disturb the photosynthesis process. The behaviour of dyes in the environment depends on their chemical structure, concentration, solubility, and degradation.

Katheresan et al. (2018) state that the complex and stable chemical composition of synthetic dyes creates difficulties in dye-containing wastewater treatment. Thus, the treatment of such effluents becomes necessary.

Methyl Violet and Crystal Violet are triarylmethane dyes known to possess high colour strength and permanence in aqueous media. Hence, their removal from wastewater becomes environmentally relevant. The adsorption process of the dye is affected by numerous factors such as adsorbent properties, pH of solution, temperature, contact time, dose of the adsorbent, and initial concentration of dye. According to Yagub et al. (2014), it is important to note that the process of dye adsorption is significantly influenced by the physicochemical properties of the dye and adsorbent.

There are many methods used in dye removal, such as coagulation-flocculation, membrane filtration, ion exchange, electrochemical treatment, advanced oxidation, and biological treatment. Although these methods work, in some cases they might consume too much energy or chemicals and produce secondary waste. In this way, adsorption process becomes interesting due to its simplicity and efficiency in removing various kinds of dyes (Piaskowski et al., 2018; Yagub et al., 2014).

Activated carbon adsorbent material is very popular because of its large surface area and adsorption capacity. Nevertheless, the cost of manufacturing and regeneration of this substance makes the search for cheap and environmental friendly alternates possible. The residues of agricultural production and industrial processes can be good candidates due to their abundance and availability. Crini (2006) noted the possibility of using different types of cheap materials for removing dyes, while Yagub et al. (2014) focused on waste-derived materials as adsorbents.

Sugarcane bagasse is one of the agro-industries residues that accumulate during sugar processing. Valorization of this residue into adsorbent material creates a potential to integrate waste management with wastewater treatment. Aruna et al. (2021) provided an insight into the capabilities of sugarcane bagasse biosorbents for dye removal applications and pointed out some key parameters that influence the process of adsorption such as pH, contact time, temperature, dosage of biosorbents, and initial concentration of dyes. Thermal treatment of sugarcane bagasse produces ash or bio-ash which could be used as an effective surface material for pollutant adsorption. Sugarcane bagasse ash has been studied by Patel et al. (2025) as a green adsorbent for dyes removal, while Dokkathin et al. (2025) used bagasse ash as the raw material for silica-based adsorbents.

Under these circumstances, the current study explores the possibility of using bioash extracted from sugarcane bagasse as an effective means of removing dyes, specifically Methyl Violet and Crystal Violet, from aqueous solutions. In order to determine the effect of different parameters such as pH, time, temperature, and bioash dosage on dye removal, the performance of bioash was studied.

Methodology

Synthesis of Bioash:

Bioash employed in the experiment was obtained through the combustion process of dried bagasse from the sugarcane plant. First of all, bagasse was dried before being burnt in the muffle furnace at about 500°C. This process led to the formation of inorganic ash that contained silica and carbonates due to the presence of a reduced amount of oxygen.

Preparation of Dye Solutions:

Two types of dyes, Methyl violet and Crystal violet, were used as model contaminants to investigate the adsorption efficiency of the biochar. The individual stock solution of each dye was prepared using a concentration of 50 ppm by mixing the respective quantities of dye powder in distilled water. The concentration was selected to mimic the actual dye concentrations present in industries. The solutions were then stored in the dark to avoid photolysis reactions.

Adsorption Experiments:

Batch adsorption experiments were conducted in order to evaluate the performance of bioash in the removal of dyes such as Methyl Violet and Crystal Violet in the presence of varied experimental parameters. In all experiments, the weight of bioash was introduced into 100 ml of the dye solution in a conical flask and shaken thoroughly to achieve even mixing. Samples were taken at selected times and the concentration of the remaining dye was determined through spectroscopy.

pH Variation:
In order to evaluate the effect of pH on the adsorption process, experiments were done at three different pH values namely 5, 7 and 9. The pH of each dye solution was adjusted by introducing 0.1 M HCl or 0.1 M NaOH before adding bioash. The pH is an important factor because it affects the surface charge of the adsorbent and the state of ionization of the dye molecule.

Contact Time:
The study of the influence of contact time on dye adsorption was done by exposing the bioash to dye solutions at varying times such as 30 minutes, 45 minutes, and 90 minutes, after which samples were taken and analyzed to determine the amount of dye adsorbed at equilibrium..

Temperature Effect:
Dye adsorption tests were conducted at three different temperatures such as 15°C, 30°C, and 45°C to observe the effect of temperature on the process of dye adsorption. It was believed that variation in temperature would have an effect on the mobility of dye molecules and the interaction between dye and adsorbent.

Bioash Dosage:
For determination of the best adsorbent dose, three different doses of bioash were used (50 mg, 75 mg, and 100 mg) against different dyes.

Determination of Adsorption Efficiency:
The adsorption efficiency (%) was calculated for each dye using the following formula:

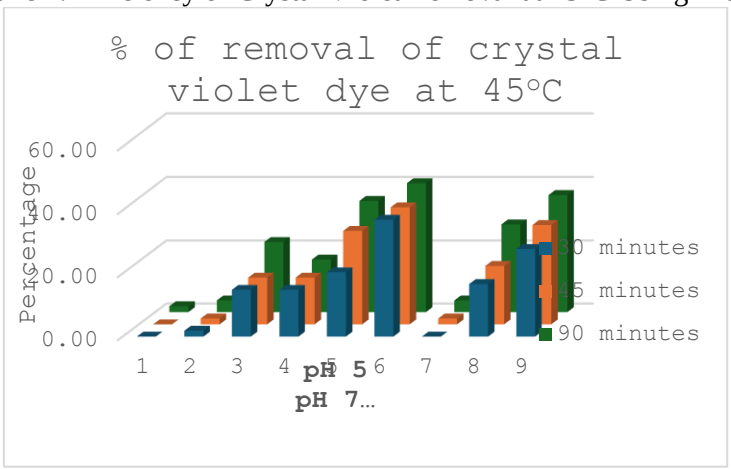
Adsorption Efficiency:
The adsorption efficiency was calculated using the following formula:

$$\text{Adsorption Efficiency (\%)} = \frac{\text{Absorbance(control)- Absorbance after treatment}}{\text{Absorbance(control)}} \times 100$$

Results
Effect of Temperature on the Adsorption Efficiency of Crystal Violet Dye Using Bioash

At 45°C
At 45°C, the dye removal efficiency was relatively moderate (Figure 1). After 30 minutes, the removal percentage ranged from 0% to 37.04%. With increasing contact time to 90 minutes, the removal efficiency improved, reaching a maximum of 40.74%. The highest removal was observed at pH 7 after 90 minutes. Initial removal was minimal at lower pH, while slightly alkaline pH (7–9) showed better adsorption of Crystal Violet (Table 1).

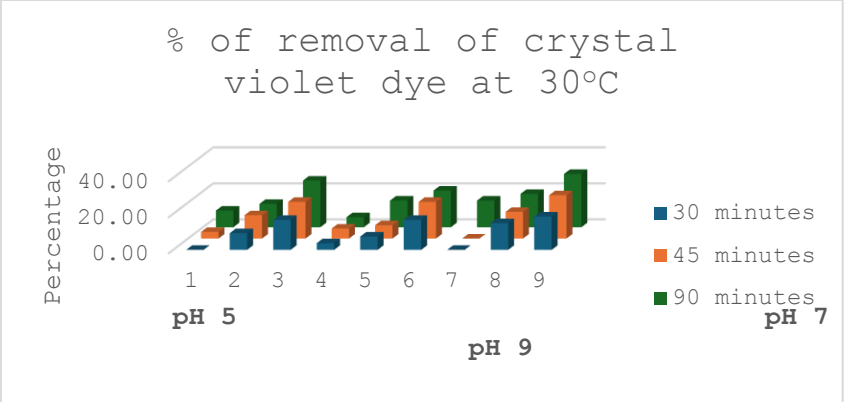
Figure 1: Efficiency of Crystal Violet Removal at 45°C Using Bioash



At 30°C

At 30°C, the dye removal was slightly less compared to 45°C (Figure 2). After 30 minutes, the removal ranged from 0% to 18.52%. At 90 minutes, the maximum removal percentage reached 29.63%. The best performance was seen at pH 9, indicating that alkaline pH favored Crystal Violet removal at this temperature as well. Removal increased with time across all pH levels, but the extent of adsorption was generally lower than at 45°C (Table 1).

Figure 2: Efficiency of Crystal Violet Removal at 30°C Using Bioash



At 15°C

At 15°C, the bioash still showed good removal capacity, especially at longer contact times (Figure 3). After 30 minutes, removal ranged between 0% and 27.78%. At 90 minutes, the removal efficiency increased, achieving a maximum of 42.59% at pH 7. Interestingly, at 15°C, the bioash performed comparably or even better than at 30°C, suggesting that lower temperatures may still support effective dye adsorption under optimal pH conditions (Table 1).

Figure 3: Efficiency of Crystal Violet Removal at 15°C Using Bioash

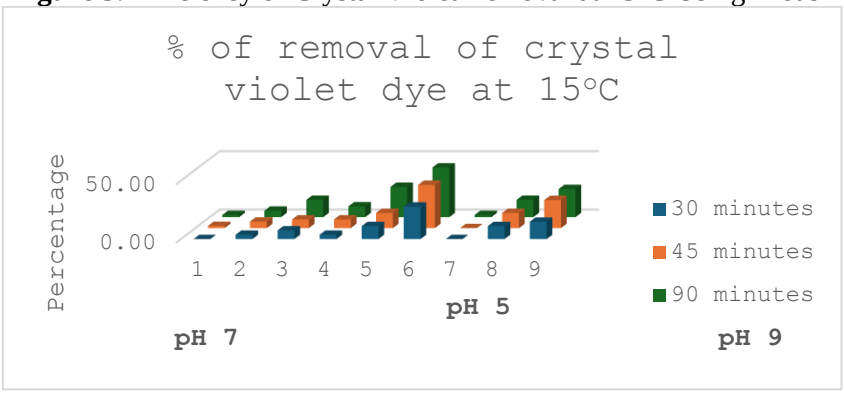


Table 1: Crystal Violet Dye Removal Efficiency by Sugarcane Bagasse Bioash at Various Temperatures and Contact Times

		Percentage of removal		
Temperature	**pH**	**30 minutes**	**45 minutes**	**90 minutes**
45°C	5.00	0.00	0.00	1.85
	5.00	1.85	1.85	3.70
	5.00	14.81	14.81	**22.22**
	7.00	14.81	14.81	16.67
	7.00	20.37	29.63	35.19
	7.00	37.04	37.04	**40.74**
	9.00	0.00	1.85	3.70
	9.00	16.67	18.52	27.78

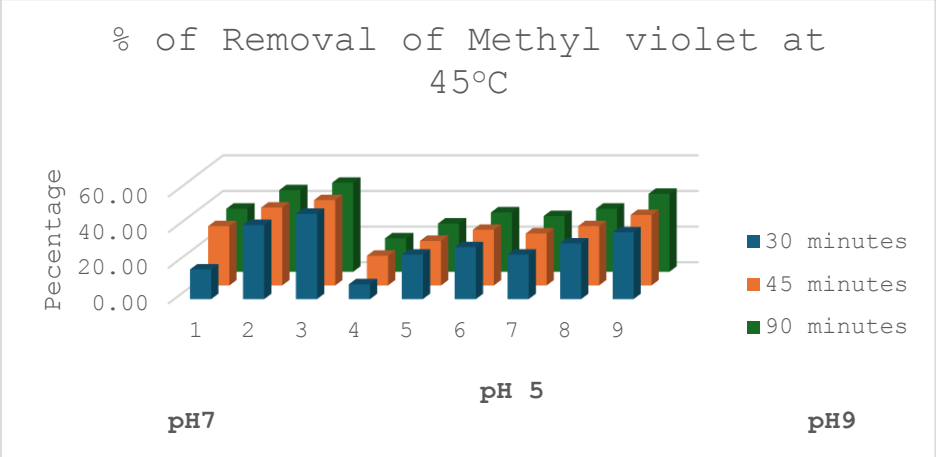
	9.00	27.78	31.48	**37.04**
30°C	5.00	0.00	3.70	9.26
	5.00	9.26	12.96	12.96
	5.00	16.67	20.37	**25.93**
	7.00	3.70	5.56	5.56
	7.00	7.41	7.41	14.81
	7.00	16.67	20.37	**20.37**
	9.00	0.00	0.00	14.81
	9.00	14.81	14.81	18.52
	9.00	18.52	24.07	**29.63**
15°C	5.00	0.00	1.85	1.85
	5.00	3.70	5.56	5.56
	5.00	7.41	7.41	**14.81**
	7.00	3.70	7.41	9.26
	7.00	11.11	12.96	25.93
	7.00	27.78	37.04	**42.59**
	9.00	0.00	0.00	1.85
	9.00	11.11	12.96	14.81
	9.00	14.81	24.07	**24.07**

Effect of Temperature on the Adsorption Efficiency of Methyl Violet Dye Using Bioash

At 45°C:

The removal efficiency of methyl violet dye increased steadily with time. After 30 minutes, the removal percentages ranged from 8.33% to 47.92% across different pH conditions. By 45 minutes, removal efficiencies further improved, reaching up to 47.92%. After 90 minutes, the maximum removal achieved was 50.00%. The highest removal was consistently observed at a higher pH, indicating that both contact time and pH significantly influenced dye removal at 45°C (Figure 4, Table 2).

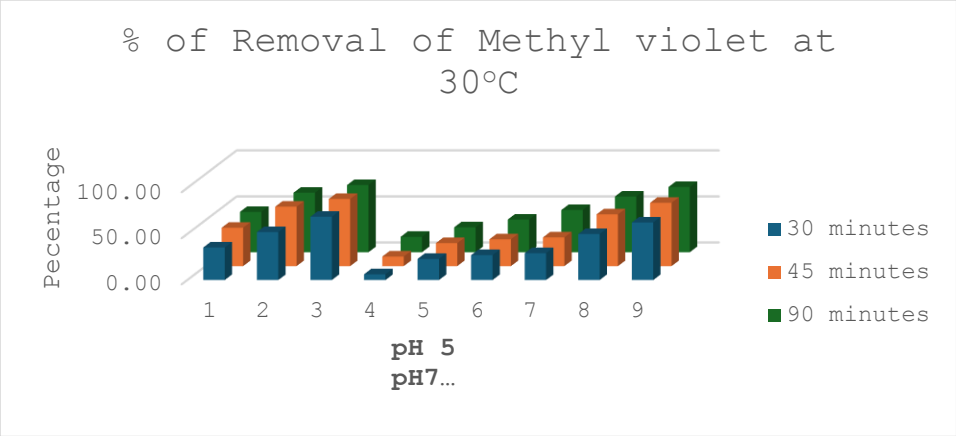
Figure 4: Efficiency of Methyl Violet Removal at 45°C Using Bioash



At 30°C:

At 30°C, the removal efficiencies were comparatively higher than at 45°C. After 30 minutes, removal ranged from 6.25% to 68.75%. A notable improvement was observed by 45 minutes, with removal reaching up to 72.92%, and this level was maintained after 90 minutes as well. The maximum removal efficiency of 72.92% was seen after both 45 and 90 minutes, suggesting good adsorption stability over time (Figure 5, Table 2).

Figure 5: Efficiency of Methyl Violet Removal at 30°C Using Bioash



At 15°C:
At 15°C, the initial removal was relatively low, with some conditions showing 0% removal at 30 minutes. However, with time, the removal efficiency improved, reaching up to 45.83% after 30 minutes and up to 60.42% after 90 minutes. The best performance was observed at 90 minutes, demonstrating that longer contact time was critical for effective dye removal at lower temperatures (Figure 6, Table 2).

Figure 6: Efficiency of Crystal Violet Removal at 15°C Using Bioash

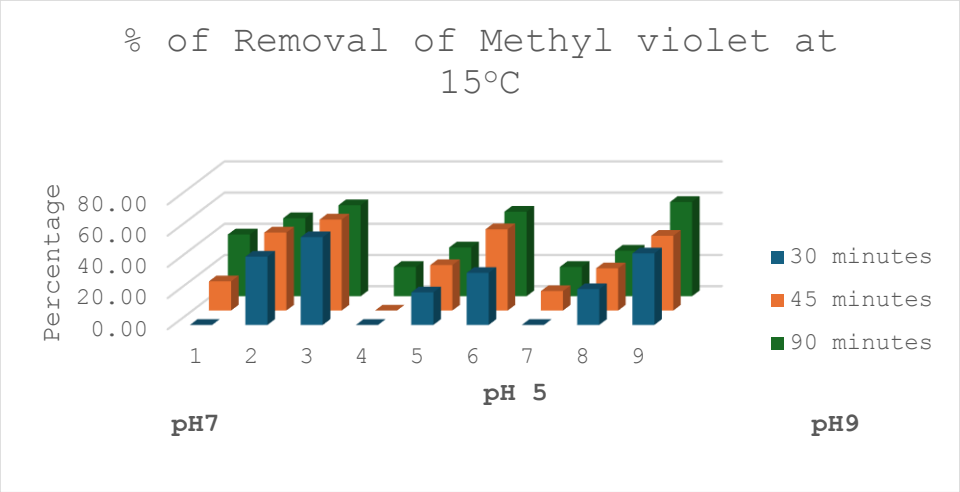


Table 2: Methyl Violet Dye Removal Efficiency by Sugarcane Bagasse Bioash at Various Temperatures and Contact Times

		Percentage of removal		
Temperature	**pH**	**30 minutes**	**45 minutes**	**90 minutes**
45°C	5.00	16.67	33.33	35.42
	5.00	41.67	43.75	45.83
	5.00	47.92	47.92	**50.00**
	7.00	8.33	16.67	18.75
	7.00	25.00	25.00	27.08
	7.00	29.17	31.25	**33.33**
	9.00	25.00	29.17	31.25
	9.00	31.25	33.33	35.42
	9.00	37.50	39.58	**43.75**
30°C	5.00	35.42	41.67	43.75
	5.00	52.08	64.58	64.58

	5.00	68.75	72.92	**72.92**
	7.00	6.25	10.42	16.67
	7.00	22.92	25.00	27.08
	7.00	27.08	29.17	**35.42**
	9.00	29.17	31.25	45.83
	9.00	50.00	56.25	60.42
	9.00	62.50	68.75	**70.83**
15°C	5.00	0.00	18.75	39.58
	5.00	43.75	50.00	50.00
	5.00	56.25	58.33	**58.33**
	7.00	0.00	0.00	18.75
	7.00	20.83	29.17	31.25
	7.00	33.33	52.08	**54.17**
	9.00	0.00	12.50	18.75
	9.00	22.92	27.08	29.17
	9.00	45.83	47.92	**60.42**

Discussion

In the present study, it has been shown that the bioash obtained from sugarcane bagasse had the ability to remove the cationic dyes Methyl Violet (MV) and Crystal Violet (CV). The removal of the dye depends on the time of contact, temperature and pH, implying that the adsorption reaction was affected by the physicochemical environment of the dye-adsorbent system. The effect of time on the increase in dye removal in the present study can be explained by the fact that more adsorption sites were available during the early stages, after which these sites were gradually occupied by the dye molecules. This type of dependence of the removal efficiency on time has been widely reported for inexpensive biomass-based adsorbents. According to Yagub et al. (2014), contact time, pH, temperature, dosage of adsorbent, and initial dye concentration are some of the important factors affecting the adsorption of the dye.

In the current study, the highest removal efficiency for MV was 72.92%, at 30°C in 90 minutes, while the highest removal for CV was 40.74%, at 45°C, pH 7 and 90 minutes. The higher removal efficiency of MV than CV implies that there were differences in the manner in which the two dyes bound to the bioash surface. Such differences could be attributed to differences in molecular structures, sizes and availability of adsorption sites. However, since there was no surface analysis performed in the current study, the specific interactions between MV and CV are not known.

The influence of temperature varied between the two dyes. The percentage of MV removed rose from 60.4% at 15°C to 72.92% at 30°C but fell to 50% at 45°C. It is evident that 30°C offered better conditions for the removal of MV in the tested temperature range. Conversely, the highest percentage removal of CV was achieved at 45°C; however, a fairly high percentage removal of 42.6% was realized at 15°C, which is higher than the 29.6% at 30°C. The above findings show that temperature does not always affect different dyes in the same way. Yagub et al. (2014) also reiterated that temperature affects different dyes and adsorbents differently, depending on the interactions between them.

The influence of pH was most pronounced on CV, where the highest removal of 40.74% was achieved at pH 7. The change in pH levels could affect the surface properties of the adsorbent as well as the interaction between the dye and the surface sites available for adsorption. Due to the cationic nature of CV, variations in the surface charge could affect the adsorption behavior of this dye. However, without information about the zeta potential and pH pzc values, it is difficult to verify the effect of electrostatic interactions. According to Vyavahare et al. (2019), the maximum sorption of CV was 99.85%, and this was achieved using mango-leaf biochar produced at 800°C, pH 8, and 47°C within 48 minutes with BET surface area of 168.23 m^2/g and pHpzc of 7.7.

The outcomes of the study can also be contrasted to other research works where adsorbents obtained from sugarcane-bagasse were used. The study conducted by Mahdi et al. (2023) considered the removal of CV by using biochar obtained from sugarcane bagasse at temperatures of 500 and 650 degrees Celsius.

According to the findings of their research work, the process of CV adsorption could be characterized by the pseudo-second-order model with R^2 equaling 1.000 and 0.9998 at those temperatures, respectively. It means that the conversion of bagasse into biochar might create an adequate surface for adsorbing CV.

In the case of MV, the adsorption capacity was determined as 125 mg/g using H_3PO_4 activated carbon of sugarcane bagasse/$Al(OH)_3$ composite by Siddiqui et al. (2022). The Freundlich model was found suitable for describing the adsorption equilibrium of MV, implying that the adsorption occurs on heterogeneous surfaces, and the adsorbent can be reused up to five adsorption-desorption cycles. In a similar vein, El-Dars et al. (2022) prepared a chemically modified cellulose-based adsorbent from sugarcane bagasse and found out the maximum adsorption capacity of CV to be 107.5 mg/g. Adsorption was observed to follow pseudo-second-order kinetics with an equilibrium capacity of 59.3 mg/g.

The discrepancy between the current findings and these stated adsorption capacities needs to be carefully interpreted as percentage removal and adsorption capacity (mg/g) are two different performance measures and are dependent on various experimental conditions such as initial dye concentration, amount of adsorbent used, and volume of solutions. Hence, the current maximum removal percentages of 72.92% for MV and 40.74% for CV should not directly be compared with the adsorption capacities of the modified adsorbents. Kaur et al. (2018) and Aruna et al. (2021) have stressed that sugarcane bagasse and other agricultural wastes can be cost-effective biosorbents whereas chemical/physical modifications can enhance their performance for dye removal.

In conclusion, the current research shows that sugarcane bagasse bioash can serve as an adsorbent that can effectively remove MV and CV without major changes in chemical composition. Using such an agricultural waste material also opens up possibilities for adding value to industrial waste from the sugarcane processing industry. Nonetheless, additional characterization by BET, FTIR, SEM-EDS, XRD, and zeta potential techniques in addition to kinetic and isotherm modeling and adsorption process regeneration will have to be done to understand the mechanism of adsorption and improve the efficiency of removal..

Conclusion

This study demonstrates that sugarcane bagasse-derived bioash can effectively reduce dye loads under mild conditions. Its simple preparation, low cost, and reasonable efficiency make it a promising preliminary treatment before advanced wastewater treatment processes. Further surface modification could improve its adsorption capacity and support its use as a sustainable agro-waste-based adsorbent.

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ROTHIA MUCILAGINOSA PERITONITIS IN AN OTHERWISE HEALTH PATIENT: A CASE REPORT

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ABSTRACT

Introduction: We present an unusual case of Rothia muciolaginosa peritonitis, mimicking appendicitis. While acute appendicitis is a common surgical presentation, other differential diagnosis of peritonitis should be considered.

Case Presentation: A 42-year-old female, previously well, presented with a six day history of lower abdominal pain, that had worsened over two days, with associated nausea and fevers. On presentation to Emergency, the patient was febrile and tachycardic, with right-sided abdominal tenderness but no peritonism. Bloods showed a raised white cell count (19 x10^9/L) and CRP of 230 mg/L. Contrast-enhanced CT abdomen/pelvis demonstrated a hyperaemic appendix with trace pelvic free fluid, favouring a diagnosis of acute appendicitis. She proceeded to urgent laparoscopic appendicectomy. However, intraoperatively, a significant volume of frank pus was identified within the pelvis and right para-colic gutter. The appendix itself was only mildly inflamed, likely reactive. A laparoscopic washout was performed and the appendix removed. Peritoneal fluid microscopy, culture and sensitivity grew Rothia mucilaginosa, broadly sensitive.

Discussion: Rothia mucilaginosa is a Gram-positive organism of the normal oral and upper respiratory flora, occasionally implicated in bacteraemia, endocarditis and infections in immunocompromised hosts, but rarely reported as a cause of intra-abdominal infection. The only reports are in peritoneal dialysis patients or patients who are immunocompromised.

Conclusion: Rothia mucilaginosa is not a recognised cause of peritonitis in otherwise healthy and immune-competent patients. To our knowledge this case is a novel report of R mucilaginosa causing intra-abdominal infection. Clinicians should be aware of atypical organisms causing unusual infections and the potential to mimic other more common pathology.

EFFECT OF ANTIEPILEPTIC DRUGS IN COGNITIVE FUNCTIONS, ANXIETY, AND HEMATOLOGICAL PARAMETERS IN MICE

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Abstract
Antiepileptics are a group of substances widely used in medicine, as they are needed for the prevention and control of epileptic seizures. In the scientific literature, they are known for their action in reducing the excessive electrical activity of neurons in the brain, making seizures more widespread and impulsive. In these analyses, the two first generations of antiepileptics, diazepam and tegretol, are effective and have different effects on healthy mice in changing anxiety and cognitive functions, in mice - Mus musculus (Swiss albino). The research aims to determine whether the consumption of antiepileptics in the full fund of 30 days of the attack in relation to anxiety, cognitive comments. The assessment of cognitive parameters was done through the Open Field test which makes the comment of anxiety and locomotor activity in mice, as thigmotaxis animals, with the treated groups resulting in a reduction of anxiety without gender difference between mice but with the difference with the control group. Also the effect of its effect on the understanding of the knowledge of the New Object Recognition (NOR), where it was found that the rats treated with these substances show a greater preference for the old object, related to other impairments in the discrimination index. The rats were administered controlled doses, where there is no time at the end of the experiment, the measurement and results of hematological parameters were made through hemogram and spectrophotometric measurements. It is worth evaluating and observing possible differences in the nature of the gender. The experimental groups showed significant changes in hematological parameters in contrast to the control group.
Keywords: Antiepileptics, Epilepsy, Cognitive functions, Anxiety, Mice, Brain anatomy.

INTEGRATING COMPUTATIONAL BIOLOGY AND MICROBIAL METABOLITES FOR CLIMATE-RESILIENT PLANT GROWTH

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Abstract
Climate change is intensifying the frequency and severity of drought stress, posing a major threat to crop productivity, biomass accumulation, and global food security. Developing sustainable strategies to improve plant resilience under water-limited conditions therefore requires a better understanding of the molecular mechanisms underlying plant–microbe interactions. In this context, computational biology provides powerful approaches for rapidly exploring molecular interactions, predicting biological functions, and identifying promising microbial metabolites with potential applications in climate-resilient agriculture. The present study highlights the integration of computational approaches with microbial metabolite profiling to investigate the potential of bacterial metabolites for improving drought tolerance and plant growth. Metabolites produced by the plant growth-promoting bacterium *Kocuria oceani* AT-1 were computationally evaluated against the maize (*Zea mays* L.) UGT706F8 glycosyltransferase protein (PDB ID: 7Q3S), a potential molecular target associated with plant growth regulation. Molecular docking was employed to screen microbial metabolites and characterize their interactions with the target protein, followed by molecular dynamics simulations to assess the stability and behavior of selected ligand–protein complexes. Among the screened metabolites, 4-tetradecanoyl-2,6-piperazinedione and 3-benzylhexahydropyrrolo(1,2-a)pyrazine-1,4-dione demonstrated favorable binding affinities of -7.5 ± 0.33 and -8.5 ± 0.36 kcal/mol, respectively, compared with the plant growth regulators indole-3-acetic acid and abscisic acid. Molecular dynamics simulations further supported the stability of these interactions, while MM-GBSA analysis indicated favorable binding energetics. Overall, the findings demonstrate how computational biology can bridge microbial metabolite discovery and molecular-level understanding of plant responses to drought. Integrating *in silico* screening with experimental validation may accelerate the identification of microbial-derived bioactive compounds and contribute to the development of sustainable, climate-resilient crop production strategies. This computational framework offers a promising pathway toward precision plant–microbe engineering and climate-smart agriculture.

Keywords: Drought stress, crop production, plant growth, bacterial metabolites, stress biology, molecular docking, molecular dynamics simulation.

DEVELOPMENT OF A METAMATERIAL-BASED MICROWAVE SENSOR FOR NON-INVASIVE AND NON-CONTACT BLOOD GLUCOSE MONITORING

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ABSTRACT

Background

Continuous blood glucose monitoring is essential for effective diabetes management; however, conventional glucose monitoring techniques commonly require invasive or minimally invasive procedures that may cause discomfort and limit frequent measurements. Microwave sensing offers a promising alternative for non-invasive glucose estimation by detecting changes in the dielectric properties of biological tissues associated with variations in glucose concentration. This study aims to develop a metamaterial-enhanced microwave sensor capable of improving electromagnetic field confinement and sensitivity for continuous non-contact blood glucose monitoring.

Materials and Methods

A metamaterial-enhanced microwave resonator was designed and analyzed for glucose sensing. The proposed sensor was modeled using an electromagnetic simulation environment and integrated with a multilayer biological tissue model representing the skin, fat, muscle, and blood-containing tissue layers.

Different glucose concentrations were considered to investigate their effects on the sensor's electromagnetic response. Key parameters, including resonant frequency, reflection coefficient (S11), bandwidth, and quality factor, were analyzed. The effect of the sensor-to-skin distance was also investigated to evaluate the feasibility of non-contact operation and determine an appropriate sensing configuration.

Results

The simulation results demonstrate that variations in glucose concentration produce measurable changes in the electromagnetic response of the proposed metamaterial-enhanced sensor. The resonant characteristics and S11 response exhibit detectable shifts with changes in glucose concentration, indicating the potential of the proposed structure for glucose estimation. The metamaterial configuration enhances electromagnetic field concentration around the sensing region and improves the interaction between the microwave field and the biological tissue model. The analysis of different sensor-to-skin distances further demonstrates the feasibility of non-contact operation while identifying the influence of separation distance on sensing sensitivity.

Conclusion

The proposed metamaterial-enhanced microwave sensor demonstrates promising potential for continuous non-contact blood glucose estimation. The combination of metamaterial-based electromagnetic enhancement and microwave sensing may provide a compact and low-cost approach for future non-invasive glucose monitoring systems. Further experimental validation using tissue phantoms and human measurements is required to assess the accuracy, repeatability, and clinical applicability of the proposed approach.

Keywords: Metamaterial; Microwave Sensor; Blood Glucose Monitoring; Non-Contact Sensing; Non-Invasive Monitoring; Biomedical Sensors; Dielectric Properties.

EVALUATION OF A SEASONAL INFLUENZA VACCINATION CAMPAIGN IN PRIMARY HEALTHCARE SETTINGS IN ALGERIA: THE EXPERIENCE OF EL MADHER DISTRICT, BATNA, 2025–2026

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ABSTRACT

Background

Seasonal influenza remains a major public health challenge worldwide, particularly among high-risk populations. Vaccination is the most effective preventive strategy; however, evidence regarding the performance of influenza vaccination campaigns in Algerian primary healthcare settings remains scarce. This study aimed to evaluate the effectiveness and operational performance of the 2025–2026 seasonal influenza vaccination campaign conducted in the El Madher Primary Health Care Establishment, Batna Province, Algeria.

Methods:A descriptive cross-sectional evaluation was conducted using official campaign records and two structured questionnaires administered to vaccinated individuals and healthcare professionals involved in the campaign. The assessment focused on vaccination coverage, vaccine stock utilization, demographic and clinical characteristics of vaccine recipients, patient satisfaction, and organizational performance.

Results: During the 51-day campaign, 2,650 doses of seasonal influenza vaccine were administered, corresponding to an overall vaccination coverage of 5.3% in a population of approximately 49,000 inhabitants. Coverage reached 37.2% among adults aged ≥65 years and 10.8% among healthcare workers. Vaccine stock utilization was optimal, with 100% of available doses administered and no wastage reported. Older adults and individuals with chronic diseases accounted for more than 85% of vaccinated recipients. Among surveyed vaccinees, 78.8% reported being satisfied or very satisfied with the services provided, while 84.8% stated they would recommend influenza vaccination to others. Furthermore, 90% of healthcare professionals reported that no adverse events occurred during the campaign.

Conclusions: The campaign demonstrated excellent logistical performance, complete vaccine stock utilization, and a favourable safety profile. Nevertheless, vaccination coverage remained substantially below international targets, particularly among priority groups. Strengthening public awareness, increasing healthcare worker engagement, and improving communication strategies are essential to enhance vaccine uptake and maximize the public health impact of future influenza vaccination campaigns.

Keywords: Influenza vaccination; Vaccination coverage; Campaign evaluation; Primary healthcare; Public health; Algeria.

MICROPLASTIC CONTAMINATION IN CLARIAS GARIEPINUS AND OREOCHROMIS NILOTICUS FISHES AND ASSESSMENT OF POTENTIAL HEALTH RISKS ASSOCIATED WITH THEIR CONSUMPTION FROM MAIRUWA RESERVOIR, FUNTUA, KATSINA STATE, NORTHWESTERN NIGERIA

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ABSTRACT
Microplastic pollution has emerged as a critical environmental threat to freshwater ecosystems and human health, yet empirical data from Sub-Saharan Africa remain scarce. This study evaluated microplastic contamination in *Clarias gariepinus* and *Oreochromis niloticus* from Mairuwa Reservoir, Northwestern Nigeria, and assessed potential health risks associated with fish consumption. Fish samples (n=240) were collected monthly (April–September 2025) from nine stations. Tissues (liver, gill, flesh) were analyzed using wet peroxide oxidation, density separation, vacuum filtration, and Fourier-transform infrared spectroscopy (FTIR). Health risks were quantified using Estimated Daily Intake (EDI), Polymer Hazard Index (PHI), and Cumulative Risk Index (CRI). Total microplastic concentrations were 298±34 counts/fish in *C. gariepinus* and 253±28 counts/fish in *O. niloticus*. FTIR identified six polymer types: polyethylene (PE) 14.8%, polypropylene (PP) 16.8%, polyethylene terephthalate (PET) 17.8%, polystyrene (PS) 19.8%, polyamide (PA) 13.8%, and polyvinyl chloride (PVC) 17.1% in *C. gariepinus*; and PE 15.0%, PP 14.2%, PET 19.4%, PS 13.0%, PA 20.9%, PVC 17.4% in *O. niloticus*. Polymer distribution reflected species-specific feeding behavior: benthic *C. gariepinus* showed higher PS and PVC, while water-column *O. niloticus* exhibited greater PA and PET. Health risk assessment revealed low risk from fish consumption (*C. gariepinus*: EDI=0.851 counts/kg bw/day, PHI=2.94, CRI=0.025; *O. niloticus*: EDI=0.723, PHI=2.83, CRI=0.021). The study concludes that fish from Mairuwa Reservoir remain relatively safe for consumption under current contamination levels, though continuous monitoring is essential. These findings provide critical baseline data for microplastic research in Nigerian freshwater ecosystems and inform evidence-based policy for food safety and environmental management.

Keywords: Microplastics, Freshwater fish, Health risk assessment, Polymer hazard index, Mairuwa Reservoir.

1. Introduction
Microplastics (plastic particles <5 mm) have emerged as pervasive environmental contaminants of global concern, with their presence documented across diverse aquatic ecosystems from polar regions to urban water bodies (Koelmans *et al.*, 2019; Rochman *et al.*, 2019). These particles originate from primary sources (manufactured microbeads, resin pellets) and secondary sources (degradation of larger plastic items) (Atugoda *et al.*, 2021). Freshwater ecosystems, particularly reservoirs serving as drinking water sources and fisheries, are increasingly recognized as significant sinks and conduits for microplastic pollution (Horton *et al.*, 2017; Wong *et al.*, 2020).
The ecological and human health implications of microplastic contamination are profound.

Aquatic organisms, including fish, ingest microplastics through direct consumption, filter-feeding, or trophic transfer, leading to physical damage (e.g., gastrointestinal blockage, false satiety), chemical toxicity from polymer additives (e.g., phthalates, bisphenol A, styrene), and potential translocation of particles to tissues (Barboza *et al.*, 2018; Lu *et al.*, 2016). Furthermore, microplastics act as vectors for adsorbed environmental pollutants (heavy metals, persistent organic pollutants) and pathogenic microorganisms, amplifying their ecotoxicological impacts (Yuan *et al.*, 2020). The trophic transfer of microplastics through food chains raises significant concerns regarding human exposure, particularly through seafood consumption (Carbery *et al.*, 2018; Miller *et al.*, 2020).

Sub-Saharan African freshwater ecosystems remain critically understudied regarding microplastic contamination, with Nigeria presenting a notable knowledge gap despite its large population, rapid urbanization, and increasing plastic waste generation (Vanapalli *et al.*, 2021; Oladeji *et al.*, 2025). Mairuwa Reservoir, located in Funtua, Katsina State, Northwestern Nigeria, serves as a vital water source for domestic, agricultural, and industrial activities, supporting local livelihoods and food security. However, the reservoir faces multiple anthropogenic pressures including urban runoff, agricultural discharge, domestic waste inputs, and fishing activities—conditions conducive to microplastic pollution (Xiang *et al.*, 2022). Despite its ecological and socioeconomic importance, no empirical data exist on microplastic contamination in this reservoir, its bioaccumulation in resident fish species, or associated human health risks.

Mairuwa Reservoir (Latitude: 11.5204° N, Longitude: 7.3116° E) is a critical freshwater source in Funtua, Katsina State, Nigeria, supporting domestic, agricultural, and industrial activities for thousands of residents. The reservoir is situated within a catchment characterized by increasing urbanization, agricultural intensification, and inadequate solid waste management practices (Vanapalli *et al.*, 2021). These anthropogenic activities represent potential pathways for microplastic entry into the reservoir through surface runoff, direct littering, atmospheric deposition, and effluent discharge from surrounding settlements. The reservoir's importance as a drinking water source and fishing ground makes it particularly vulnerable to contamination, with serious implications for public health and food security. However, no empirical data exist on the extent of microplastic pollution in this critical water body.

Pathways of microplastic entry into Mairuwa Reservoir are numerous and interconnected. Urban runoff from Funtua town and surrounding settlements carries plastic debris, microfibers from textiles, and microbeads from personal care products directly into the reservoir during rainfall events. Agricultural activities in the catchment contribute through plastic mulch film degradation, fertilizer application, and irrigation with contaminated water (Kumar *et al.*, 2020). Atmospheric deposition of microplastics from urban and industrial dust further contributes to the contaminant load (Dris *et al.*, 2016). Additionally, inadequate waste disposal practices, including open dumping and burning of plastics, create secondary sources of microplastic pollution. Fishing activities within the reservoir introduce synthetic nets and ropes, which degrade into microplastic fibers over time. These multiple pathways collectively contribute to the reservoir's vulnerability to microplastic contamination, yet the relative contribution of each source remains unquantified.

Previous studies on microplastic pollution in Nigerian freshwater systems are limited but growing. Oladeji *et al.* (2025) reported seasonal dynamics in Aarin River, Southwestern Nigeria, where microplastic levels were notably higher during the rainy season due to increased runoff. Yahaya *et al.* (2024) employed FTIR spectroscopy in Birnin Kebbi rivers, Nigeria, reporting polyamide as the dominant polymer (50%) in water samples. Amana *et al.* (2025) assessed microplastic risks in *Clarias gariepinus* and *Oreochromis niloticus* from River Niger, Lokoja, finding species-specific accumulation patterns. Ololade *et al.* (2024) reported on microplastic particles in river sediments and water of southwestern Nigeria. Omoigberale *et al.* (2025) documented microplastics in sediment of the Ovia River, Benin City. Onaji (2025) analyzed microplastic contamination in *Oreochromis niloticus* and *Clarias gariepinus* from Lagos and Epe Lagoons. These studies collectively indicate that Nigerian freshwater systems are significantly contaminated, but the majority focus on rivers and coastal lagoons, leaving reservoirs largely unexplored.

Despite the growing body of research on microplastics in Nigerian aquatic systems, no comprehensive study has been conducted on Mairuwa Reservoir a critical water source serving thousands of residents. The seasonal dynamics of microplastic pollution, polymer characterization using FTIR for human populations reliant on the reservoir remain completely unknown.

This knowledge gap hinders the development of evidence-based policies for water quality management and public health protection. Furthermore the species-specific accumulation patterns in fish species commonly consumed by local communities have not been investigated, limiting our understanding of potential dietary exposure risks

The present study addresses this critical knowledge gap by evaluating and characterizing microplastic contamination in two commercially important fish species: *Clarias gariepinus* (African sharptooth catfish, a benthic omnivore/scavenger) and *Oreochromis niloticus* (Nile tilapia, a water-column filter feeder). These species were selected based on their contrasting feeding ecologies, economic significance, and frequent consumption by local communities. Specific objectives included: (1) quantifying microplastic concentration and distribution in fish tissues (liver, gill, flesh); (2) identifying polymer types using Fourier-transform infrared spectroscopy (FTIR); and (3) assessing human health risks through Estimated Daily Intake (EDI), Polymer Hazard Index (PHI), and Cumulative Risk Index (CRI). The findings provide critical baseline data for understanding microplastic pollution dynamics in Nigerian freshwater ecosystems and inform public health interventions for communities reliant on reservoir fisheries.

2. Materials and Methods

2.1 Study Area

Mairuwa Reservoir (Latitude: 11.5204° N, Longitude: 7.3116° E) is a critical freshwater source in Funtua, Katsina State, Nigeria, supporting domestic, agricultural, and industrial activities. The reservoir is susceptible to microplastic pollution due to urban runoff, agricultural discharge, and inadequate waste management (Vanapalli *et al.*, 2021). The reservoir has had a positive impact on the local economy by creating job opportunities in agriculture and related sectors. It has also improved the living standards of residents by enhancing food availability and access to water. Geographic coordinates were recorded using a GPS device (Garmin GPSMAP 64s) to ensure precise sampling locations (Xiang *et al.*, 2022).

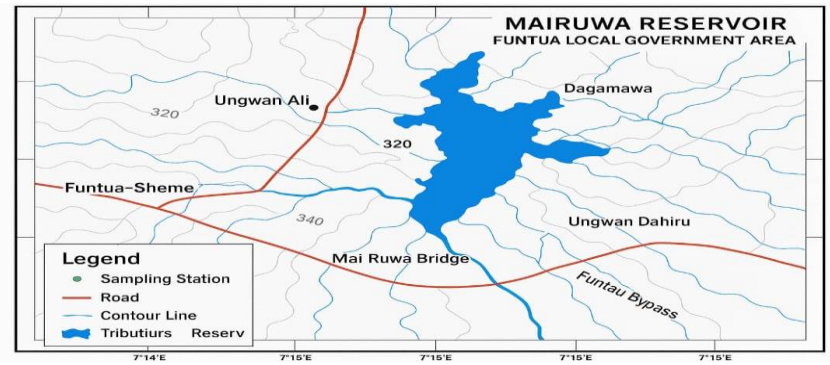


Fig 1. Map showing Mairuwa reservoir in Funtua, Katsina State.

2.2 Sampling Sites

Nine (9) sampling sites 100 m apart were selected for the collection of water and sediment in the reservoir to ensure spatial representation:

Inlet Zone – Near the primary water inflow, Shoreline Zone – Adjacent to human settlements, Central Zone – Deepest section of the reservoir, Outflow Zone – Near the discharge point, Agricultural Zone – Close to farming activities. Site selection was based on proximity to potential pollution sources (Xiang *et al.*, 2022).

2.3 Study Design

A cross-sectional field and laboratory-based study was adopted to assess microplastic contamination. The design ensures systematic data collection and analysis, following protocols established in similar studies (Ragusa *et al.*, 2021).

2.4 Sample Collection

2.4.1 Fish Sampling

A total of 120 fish specimens were collected from Mairuwa Reservoir across the six-month study period (April–September 2025). Two commercially important fish species were targeted: *Clarias gariepinus* (African catfish) and *Oreochromis niloticus* (Nile tilapia). Each month, ten (10) specimens of *C. gariepinus* and ten (10) specimens of *O. niloticus* were randomly captured from the reservoir using gill nets and baited traps, giving a monthly total of 20 fish and an overall total of 120 fish across the six months. The fish was rinsed with clean water to remove external debris and particles, placed in ice slurry for preservation, and transported to the laboratory for further analysis (Zhang *et al.*, 2023).

2.5 Laboratory Analysis (Microplastic Extraction and Identification)

2.5.1 Fish Samples

The fish samples were rinsed with distilled water before dissection. Using sterile stainless-steel tools, the flesh, liver, and gills were carefully separated. Tissue samples (5–10 g wet weight) were placed in clean glass beakers and oven-dried. The dried samples were then homogenized using a mortar and pestle. For chemical digestion, 2 g of homogenized tissue was treated with 100 mL of 10% potassium hydroxide (KOH) solution to break down proteins and lipids. The beakers were covered with aluminum foil to prevent contamination and incubated at 50–60°C for 24 hours. Following primary digestion, 200 mL of 30% hydrogen peroxide (H_2O_2) was added to decompose remaining organic material. The mixture was heated on a stirring hot plate at 50°C for 1–3 hours to accelerate the reaction before being cooled to room temperature.

The digested solution was transferred to a separation funnel, where 300 mL of saturated NaCl solution was added. The mixture was gently shaken and left undisturbed for 24 hours to allow microplastics to float to the surface. The supernatant containing floating particles was carefully collected by decanting. This solution was then vacuum-filtered through a membrane filter (1–5 µm pore size) using a suction filtration system. The filter was placed in a labeled Petri dish for examination.

Microplastics were identified and characterized under a stereomicroscope, with particles categorized by types and shapes. Polymer identification was performed using Fourier-transform infrared spectroscopy (FTIR) to confirm particle composition (Collard *et al.*, 2015; Masura *et al.*, 2015; Rochman *et al.*, 2019).

2.5.2 Polymer Identification

Microplastic particles on filters were visually inspected under a stereomicroscope (40× magnification) and classified by size, shape, and color. Polymer identification was performed using Fourier-transform infrared spectroscopy (FTIR) (PerkinElmer Spectrum Two) in attenuated total reflectance (ATR) mode. Spectra were recorded in the range 4000–500 cm^{-1} with 32 scans at 4 cm^{-1} resolution. Spectral data were compared with reference libraries to identify polymer types: polyethylene (PE), polypropylene (PP), polyethylene terephthalate (PET), polystyrene (PS), polyamide (PA/nylon), and polyvinyl chloride (PVC) (Nizzetto *et al.*, 2023; Jung *et al.*, 2018)

2.6 Health Risk Assessment

Health risks were assessed using three standardized indices:

Estimated Daily Intake (EDI): $EDI = (C \times IR) / BW$

Where C = microplastic concentration (counts/kg), IR = daily intake rate (0.05 kg fish/day for adults), BW = body weight (70 kg adult).

Polymer Hazard Index (PHI): $PHI = \Sigma(C_i \times T_i)$

Where C_i = proportion of polymer i, T_i = toxicity factor (Lithner *et al.*, 2011): PE=1, PP=2, PA=2, PET=3, PS=4, PVC=5.

Cumulative Risk Index (CRI): $CRI = (EDI \times PHI) / 100$

Risk classification: CRI <0.05 (Low), 0.05–0.15 (Moderate), 0.15–0.30 (High), >0.30 (Very High).

3. Results

3.1 Microplastic Concentration and Distribution

Table 1 presents monthly distribution of microplastic polymer types in *C. gariepinus* and *O. niloticus* tissues. Total microplastic concentrations were 298 counts/fish in *C. gariepinus* and 253 counts/fish in *O. niloticus*. *C. gariepinus* exhibited highest PS concentrations in May (14.00 ± 1.00 counts/fish) and

September (14.00 ± 1.00), while *O. niloticus* showed peak PET concentrations in June (14.00 ± 1.00) and August (14.00 ± 1.00). Significant monthly variations ($p < 0.05$) were observed across polymer types, with superscript letters (a–c) indicating statistical differences.

Table 1 presents the monthly distribution of polymer types in *Clarias gariepinus*. April recorded high PE (14.00 ± 1.00) and PP (13.00 ± 0.90). May showed elevated PS (14.00 ± 1.00). June had high PS (12.00 ± 0.80), PA (13.00 ± 0.90), and PVC (11.00 ± 0.80). July recorded the highest PET (14.00 ± 1.00) and high PA (12.00 ± 0.80). August again showed high PET (14.00 ± 1.00). September recorded high PS (14.00 ± 1.00) and moderate levels of other polymers. The significant monthly differences indicate that *C. gariepinus* ingests different polymers depending on seasonal availability and sediment resuspension.

Table 1: Monthly distribution of microplastic polymer types in Clarias gariepinus from Mairuwa Reservoir, Katsina State

Month	PE	PP	PET	PS	PA	PVC
Apr	14.00 ± 1.00^{a}	13.00 ± 0.90^{a}	7.00 ± 0.50^{b}	10.00 ± 0.70^{b}	3.00 ± 0.40^{c}	5.00 ± 0.50^{c}
May	10.00 ± 0.70^{b}	10.00 ± 0.70^{b}	8.00 ± 0.60^{b}	14.00 ± 1.00^{a}	7.00 ± 0.50^{c}	10.00 ± 0.70^{b}
Jun	5.00 ± 0.50^{c}	9.00 ± 0.60^{b}	2.00 ± 0.30^{c}	12.00 ± 0.80^{a}	13.00 ± 0.90^{a}	11.00 ± 0.80^{a}
Jul	8.00 ± 0.60^{b}	8.00 ± 0.60^{b}	14.00 ± 1.00^{a}	5.00 ± 0.50^{c}	12.00 ± 0.80^{a}	6.00 ± 0.50^{c}
Aug	2.00 ± 0.30^{c}	2.00 ± 0.30^{c}	14.00 ± 1.00^{a}	4.00 ± 0.50^{c}	1.00 ± 0.20^{c}	9.00 ± 0.60^{b}
Sep	5.00 ± 0.50^{c}	8.00 ± 0.60^{b}	8.00 ± 0.60^{b}	14.00 ± 1.00^{a}	5.00 ± 0.50^{c}	10.00 ± 0.70^{b}

Note*: Values are mean counts/fish ± SD. Different superscripts indicate significant differences ($p < 0.05$, ANOVA).*

Table 2 presents the monthly distribution of polymer types in *Oreochromis niloticus*. April had high PS (12.00 ± 0.80), PA (13.00 ± 0.90), and PVC (11.00 ± 0.80). May recorded very high PET (13.00 ± 0.90). June showed peak PET (14.00 ± 1.00) and high PA (10.00 ± 0.70). July had high PE (10.00 ± 0.70) and PS (9.00 ± 0.60). August recorded high PP (14.00 ± 1.00) and PET (14.00 ± 1.00). September showed high PE (10.00 ± 0.70), PET (13.00 ± 0.90), and PVC (14.00 ± 1.00). The dominance of PET and PE in *O. niloticus* reflects its filtration of water column particles, where these lighter polymers are more abundant.

Table 2: Monthly distribution of microplastic polymer types in Oreochromis niloticus from Mairuwa Reservoir, Katsina State

Month	PE	PP	PET	PS	PA	PVC
Apr	6.00 ± 0.50^{b}	3.00 ± 0.40^{c}	5.00 ± 0.50^{b}	12.00 ± 0.80^{a}	13.00 ± 0.90^{a}	11.00 ± 0.80^{a}
May	2.00 ± 0.30^{c}	1.00 ± 0.20^{c}	13.00 ± 0.90^{a}	2.00 ± 0.30^{c}	9.00 ± 0.60^{b}	9.00 ± 0.60^{b}
Jun	5.00 ± 0.50^{b}	1.00 ± 0.20^{c}	14.00 ± 1.00^{a}	4.00 ± 0.50^{b}	10.00 ± 0.70^{a}	3.00 ± 0.40^{c}
Jul	10.00 ± 0.70^{a}	4.00 ± 0.50^{c}	7.00 ± 0.50^{b}	9.00 ± 0.60^{a}	1.00 ± 0.20^{c}	3.00 ± 0.40^{c}
Aug	9.00 ± 0.60^{b}	14.00 ± 1.00^{a}	14.00 ± 1.00^{a}	7.00 ± 0.50^{b}	5.00 ± 0.50^{c}	6.00 ± 0.50^{b}
Sep	10.00 ± 0.70^{b}	1.00 ± 0.20^{c}	13.00 ± 0.90^{a}	3.00 ± 0.40^{c}	1.00 ± 0.20^{c}	14.00 ± 1.00^{a}

Note*: Values are mean counts/fish ± SD. Different superscripts indicate significant differences (p < 0.05, ANOVA).*

Table 3 presents the spatial distribution of polymer types in *Clarias gariepinus*. Across all stations, PS was consistently the most abundant polymer in *C. gariepinus* (10.00–10.30 counts/fish). PE, PP, PET, PA, and PVC showed similar moderate levels (7.40–8.10 counts/fish) with no significant spatial differences. The uniformity across stations indicates that *C. gariepinus* throughout the reservoir experiences similar microplastic exposure levels.

Table 3: Spatial distribution of microplastic polymer types in *Clarias gariepinus* across sampling points in Mairuwa Reservoir, Katsina State

Station	PE	PP	PET	PS	PA	PVC
SP1	7.50 ± 3.50^{b}	7.60 ± 3.20^{b}	7.80 ± 4.20^{b}	10.00 ± 3.50^{a}	7.40 ± 4.00^{b}	7.60 ± 3.40^{b}
SP2	7.70 ± 3.60^{b}	7.80 ± 3.30^{b}	8.00 ± 4.30^{b}	10.20 ± 3.60^{a}	7.60 ± 4.10^{b}	7.80 ± 3.50^{b}
SP3	7.60 ± 3.40^{b}	7.70 ± 3.20^{b}	7.90 ± 4.10^{b}	10.10 ± 3.50^{a}	7.50 ± 4.00^{b}	7.70 ± 3.40^{b}
SP4	7.80 ± 3.50^{b}	7.90 ± 3.30^{b}	8.10 ± 4.20^{b}	10.30 ± 3.60^{a}	7.70 ± 4.10^{b}	7.90 ± 3.50^{b}
SP5	7.60 ± 3.40^{b}	7.70 ± 3.20^{b}	7.90 ± 4.30^{b}	10.10 ± 3.50^{a}	7.50 ± 4.00^{b}	7.70 ± 3.40^{b}
SP6	7.70 ± 3.50^{b}	7.80 ± 3.30^{b}	8.00 ± 4.20^{b}	10.20 ± 3.60^{a}	7.60 ± 4.10^{b}	7.80 ± 3.50^{b}
SP7	7.50 ± 3.40^{b}	7.60 ± 3.20^{b}	7.80 ± 4.10^{b}	10.00 ± 3.50^{a}	7.40 ± 4.00^{b}	7.60 ± 3.40^{b}
SP8	7.80 ± 3.50^{b}	7.90 ± 3.30^{b}	8.10 ± 4.20^{b}	10.30 ± 3.60^{a}	7.70 ± 4.10^{b}	7.90 ± 3.50^{b}
SP9	7.60 ± 3.40^{b}	7.70 ± 3.20^{b}	7.90 ± 4.30^{b}	10.10 ± 3.50^{a}	7.50 ± 4.00^{b}	7.70 ± 3.40^{b}

Note*: Values are mean counts/fish ± SD. Different superscripts indicate significant differences (p < 0.05, ANOVA).*

Table 4 presents the spatial distribution of polymer types in *Oreochromis niloticus*. PET was the dominant polymer across all stations (10.00–10.30 counts/fish), followed by PVC (8.40–8.70) and PE (7.80–8.10). PP was consistently the lowest (5.40–5.70). The spatial uniformity again suggests well-mixed contamination. The clear difference between species PS dominance in *C. gariepinus* versus PET dominance in *O. niloticus* highlights the role of habitat and feeding behavior in determining microplastic uptake.

Table 4: Spatial distribution of microplastic polymer types in Oreochromis niloticus across sampling points in Mairuwa Reservoir, Katsina State

Station	PE	PP	PET	PS	PA	PVC
SP1	7.80 ± 4.80^{b}	5.40 ± 5.10^{c}	10.00 ± 4.00^{a}	6.20 ± 3.70^{b}	7.00 ± 4.60^{b}	8.40 ± 3.50^{b}
SP2	8.00 ± 4.90^{b}	5.60 ± 5.20^{c}	10.20 ± 4.10^{a}	6.40 ± 3.80^{b}	7.20 ± 4.70^{b}	8.60 ± 3.60^{b}
SP3	7.90 ± 4.80^{b}	5.50 ± 5.30^{c}	10.10 ± 4.00^{a}	6.30 ± 3.70^{b}	7.10 ± 4.60^{b}	8.50 ± 3.50^{b}
SP4	8.10 ± 4.90^{b}	5.70 ± 5.20^{c}	10.30 ± 4.10^{a}	6.50 ± 3.80^{b}	7.30 ± 4.70^{b}	8.70 ± 3.60^{b}
SP5	7.90 ± 4.80^{b}	5.50 ± 5.10^{c}	10.10 ± 4.00^{a}	6.30 ± 3.70^{b}	7.10 ± 4.60^{b}	8.50 ± 3.50^{b}
SP6	8.00 ± 4.90^{b}	5.60 ± 5.20^{c}	10.20 ± 4.10^{a}	6.40 ± 3.80^{b}	7.20 ± 4.70^{b}	8.60 ± 3.60^{b}
SP7	7.80 ± 4.80^{b}	5.40 ± 5.30^{c}	10.00 ± 4.00^{a}	6.20 ± 3.70^{b}	7.00 ± 4.60^{b}	8.40 ± 3.50^{b}
SP8	8.10 ± 4.90^{b}	5.70 ± 5.20^{c}	10.30 ± 4.10^{a}	6.50 ± 3.80^{b}	7.30 ± 4.70^{b}	8.70 ± 3.60^{b}
SP9	7.90 ± 4.80^{b}	5.50 ± 5.10^{c}	10.10 ± 4.00^{a}	6.30 ± 3.70^{b}	7.10 ± 4.60^{b}	8.50 ± 3.50^{b}

Note*: Values are mean counts/fish ± SD. Different superscripts indicate significant differences (p < 0.05, ANOVA).*

3.2 Polymer Identification through FTIR

FTIR spectral analysis confirmed polymer types in fish tissues. *C. gariepinus* tissues exhibited characteristic peaks: 3319 cm^{-1} (O-H/N-H stretching, weathered plastics), 2915/2843 cm^{-1} (aliphatic C-H, PE/PP), 1744 cm^{-1} (C=O ester, PET), 1636–1535 cm^{-1} (Amide I/II, proteins and polyamide), and 1145/1026 cm^{-1} (C-O/C-O-C, PET/PVC) (Table 2). *O. niloticus* tissues showed similar profiles with stronger PET signals (1007 cm^{-1} C-O stretch) and PA contributions (1546 cm^{-1} Amide II).

The presence of overlapping biological peaks (proteins, lipids) complicated polymer identification; however, distinct polymer-specific bands confirmed microplastic accumulation in liver, gill, and flesh tissues. Gill tissues exhibited sharper polymer peaks reflecting direct water exposure, while flesh tissues demonstrated significant bioaccumulation raising trophic transfer concerns.

Table 5: FTIR spectral assignments for fish tissues

Wavenumber (cm^{-1})	Functional Group	Polymer Type	Tissue Distribution
3319	O-H/N-H stretch	PA	Liver, Gill
2915, 2843	Aliphatic C-H	PE, PP	All tissues
1744	C=O (ester)	PET	Liver, Gill
1636-1535	Amide I/II	Polyamide (Nylon)	All tissues
1466-1411	CH_3 bending/COO^-	PET, oxidized PE	Gill, Liver
1145, 1026	C-O/C-O-C	PET, PVC	Flesh > Gill

3.3 Species-Specific Accumulation Patterns

Significant species-specific differences were observed in polymer composition. *C. gariepinus* (benthic feeder) showed dominance of PS (19.80% of total MP burden) and PVC (17.11%), while *O. niloticus* (water-column filter feeder) exhibited higher PA (20.95%) and PET (19.37%). These patterns reflect: (1) polymer density—denser PS and PVC settle in sediments accessible to benthic feeders; (2) feeding behavior—*C. gariepinus* scavenges sediment-embedded particles, while *O. niloticus* filters suspended particles in the water column (PE, PET, PA); and (3) habitat contamination—sediment in Mairuwa Reservoir showed high PA (22.06%) and PVC (15.81%), consistent with benthic exposure. Spatial analysis revealed uniform polymer distribution across all nine stations, indicating well-mixed contamination throughout the reservoir. This aligns with recent studies in Nigerian rivers and tropical reservoirs (Amana *et al.*, 2025; Oladeji *et al.*, 2025).

3.4 Health Risk Assessment

Table 6 presents the concentration calculations for each matrix. Total microplastic counts for each matrix were converted to concentration units by dividing the total counts by the mass/volume. Average fish mass was 250 g (0.25 kg), sediment ingestion rate was 0.1 kg/day, and water ingestion rate was 2 L/day (standard adult consumption).

Table 6: Concentration calculations for each sample in Mairuwa Reservouir funtua, katsina state Nigeria

Sample	Total Count	Mass/Volume	Concentration (counts/kg or counts/L)
C. gariepinus	298	0.25kg	1192 count/kg
O. niloticus	253	0.25kg	1012 count/kg
Sediment	272	1kg	272 count/kg
Water	307	1L	307 count/L

Table 7 presents the Estimated Daily Intake (EDI) summary. Water ingestion contributed the highest estimated daily intake (8.771 counts/kg bw/day), which is approximately 10 times higher than exposure through fish consumption (0.723–0.851 counts/kg bw/day). The EDI for sediment was 0.389 counts/kg bw/day.

Table 7: Estimated Daily Intake (EDI) for each sample in Mairuwa Reservouir Funtua, Katsina State Nigeria

Sample	Concentration	Intake Rate	EDI (count/kg)
C. gariepinus	1192 count/kg	0.05kg/day	0.851
O. niloticus	1012 count/kg	0.05kg/day	0.723
Sediment	272 count/kg	0.1kg/day	0.389
Water	307 count/kg	2L/day	8.771

Table 8 present the Polymer Hazard Index (PHI) calculations using polymer proportions and toxicity factors (PE = 1, PA/PP = 2, PET = 3, PS = 4, PVC = 5). *C. gariepinus* exhibited the highest PHI (2.94), followed by *O. niloticus* (2.83), water (2.78), and sediment (2.65). The higher PHI for *C. gariepinus* is primarily attributed to its higher PS content (19.80%) and PVC content (17.11%).

Table 8: Polymer Hazard Index for each sample in Mairuwa Reservouir Funtua, Katsina State Nigeria

Sample	PHI Value	Risk Interpretation
C. gariepinus	2.94	Moderate-High Hazard
O. niloticus	2.83	Moderate-High Hazard
Water	2.78	Moderate Hazard
Sediment	2.65	Moderate Hazard

Table 9 presents the Cumulative Risk Index (CRI) calculations. The CRI was calculated as CRI = (EDI × PHI) / 100. Water had the highest CRI (0.244), followed by *C. gariepinus* (0.025), *O. niloticus* (0.021), and sediment (0.010).

Table 9: Cumulative Risk Index for each sample in Mairuwa Reservouir Funtua, Katsina State Nigeria

Matrix	EDI (counts/kg bw/day)	PHI	CRI	Risk Level
Water	8.771	2.78	0.244	High Risk
C. gariepinus	0.851	2.94	0.025	Low Risk
O. niloticus	0.723	2.83	0.021	Low Risk
Sediment	0.389	2.65	0.010	Low Risk

4. Discussion

The total microplastic concentrations observed in this study (298±34 counts/fish in *C. gariepinus* and 253±28 counts/fish in *O. niloticus*) are consistent with findings from other African freshwater systems, where concentrations typically range from 120 to 680 particles/fish (Amana *et al.*, 2025; Onaji *et al.*, 2025; Oladeji *et al.*, 2025). These regional consistencies suggest that Nigerian freshwater systems are experiencing widespread microplastic contamination at levels that warrant continuous monitoring. The significantly higher microplastic burden in *C. gariepinus* ($p = 0.043$) compared to *O. niloticus* reflects species-specific feeding ecology and habitat utilization. *C. gariepinus* is a benthic omnivore and scavenger, actively foraging on sediment where denser microplastics such as polystyrene (PS: 1.04 g/cm³) and polyvinyl chloride (PVC: 1.38 g/cm³) accumulate (Sarijan *et al.*, 2021; Zhu *et al.*, 2022). In contrast, *O. niloticus* is primarily a water-column filter feeder, ingesting suspended particles including lighter polymers such as polyethylene (PE: 0.91–0.96 g/cm³) and polypropylene (PP: 0.90–0.91 g/cm³) that remain in the water column (Zhang *et al.*, 2017; Windsor *et al.*, 2019). This ecological distinction is clearly reflected in the polymer composition data: *C. gariepinus* showed higher PS (19.80%) and PVC (17.11%), while *O. niloticus* exhibited higher PA (20.95%) and PET (19.37%). The lower condition factor observed in *C. gariepinus* ($K = 0.51$) compared to *O. niloticus* ($K = 1.72$) further suggests potential physiological stress from chronic microplastic ingestion, consistent with experimental studies demonstrating reduced feeding efficiency, intestinal damage, and oxidative stress in fish exposed to microplastics (Au *et al.*, 2015; Espinosa *et al.*, 2018; Lu *et al.*, 2016).

The identification of six polymer types PE, PP, PET, PS, PA, and PVC aligns with global and regional inventories of freshwater microplastics, collectively accounting for more than 80% of global plastic production (Geyer *et al.*, 2017; Hidalgo-Ruz *et al.*, 2012). PE (14.8–15.0%) and PP (14.2–16.8%) are ubiquitous in packaging materials, and their predominance in fish tissues reflects the widespread use of single-use plastics and inadequate waste management in the reservoir catchment. The high PE/PP concentrations during May–June correspond to peak rainfall when surface runoff transports land-based debris into the reservoir, a pattern consistent with observations in Nigerian rivers (Oladeji *et al.*, 2025; Idowu *et al.*, 2025). PET (17.8–19.4%) was consistently abundant across both species, with higher proportions in *O. niloticus* (19.37%), indicating contamination from beverage bottles and synthetic textile fibers that remain suspended in the water column (Cesa *et al.*, 2017; Henry *et al.*, 2019). PS (13.0–19.8%) and PVC (17.1–17.4%) are among the most toxic polymers due to their monomer content—styrene (IARC Group 2A, probable carcinogen) and vinyl chloride (IARC Group 1, known carcinogen) (Lithner *et al.*, 2011; Rochman *et al.*, 2013). Their high proportion in *C. gariepinus* reflects sediment accumulation from building materials, packaging, and electronic waste (Shim *et al.*, 2017; Fojt *et al.*, 2020).

PA/nylon (13.8–20.9%) was the most abundant polymer in *O. niloticus* (20.95%), confirming contamination from synthetic textile fibers and abandoned fishing gear, with sources including nylon nets, ropes, and synthetic clothing (Dehaut *et al.*, 2016; Prata *et al.*, 2019; Yahaya *et al.*, 2024).

The distribution of microplastics across tissues revealed gills as the primary site of accumulation (42–45%), followed by liver (25–28%), and flesh (18–22%). This pattern is consistent with studies by Collard et al. (2015) and Rochman et al. (2015), reflecting the gill's role as the primary interface with the aquatic environment. The presence of microplastics in gills can cause physical damage, including epithelial erosion and reduced gas exchange efficiency (Espinosa *et al.*, 2018). Translocation to the liver (25–28%) raises concerns about systemic toxicity, as the liver is the primary site of detoxification and metabolic processing (Lu *et al.*, 2016; Wang *et al.*, 2019). The presence of microplastics in flesh tissues (18–22%) is particularly concerning from a food safety perspective, as these are the edible portions consumed by humans, with fibrous particles showing higher translocation potential to muscle tissues (Carbery *et al.*, 2018; Miller *et al.*, 2020).

Significant monthly variations in polymer concentrations ($p < 0.05$) reflect seasonal dynamics in microplastic input and transport. Peak concentrations during May–September correspond to the rainy season when surface runoff, flooding, and sediment resuspension mobilize terrestrial plastic debris into the reservoir, consistent with studies in Nigerian rivers and tropical reservoirs (Oladeji *et al.*, 2025; Maulidah *et al.*, 2025; Ossa-Yepes *et al.*, 2025). Spatially, microplastic distribution was uniform across all nine stations ($p > 0.05$), indicating well-mixed conditions throughout the reservoir driven by wind-induced circulation and continuous water movement. This homogeneity suggests that contamination is reservoir-wide, requiring comprehensive rather than targeted management interventions.

The health risk assessment using CRI values revealed that fish consumption poses Low Risk under current contamination levels (*C. gariepinus*: CRI = 0.025; *O. niloticus*: CRI = 0.021), consistent with global risk assessments for freshwater fish consumption (Enyoh *et al.*, 2022; Nguyen & Lin, 2025). The slightly higher risk for *C. gariepinus* is driven by its elevated PS and PVC content—polymers with toxicity factors of 4 and 5, respectively. However, for vulnerable populations including children, pregnant women, and immunocompromised individuals, the cumulative effect of chronic exposure across multiple pathways warrants caution (Barboza *et al.*, 2018; Ragusa *et al.*, 2021). The PHI values (2.65–2.94) indicate moderate to high polymer toxicity across all matrices, consistent with values reported in other Nigerian water bodies (Yahaya *et al.*, 2024; Onaji *et al.*, 2025), reflecting the contribution of PS and PVC. A critical finding is that water ingestion poses substantially higher risk than fish consumption (CRI = 0.244, High Risk), approximately ten times higher, reflecting high daily intake volume (2 L/day), continuous exposure throughout life, and population vulnerability factors. This finding has significant public health implications for communities relying on untreated reservoir water, necessitating urgent interventions including household filtration systems, centralized water treatment with microplastic removal capabilities, and regulatory frameworks aligned with emerging WHO guidelines (Padervand *et al.*, 2020; Zhang *et al.*, 2021).

The microplastic concentrations observed in this study (253–298 counts/fish) fall within the range reported in other African freshwater systems (Amana *et al.*, 2025; Onaji *et al.*, 2025), and the polymer profile (PE, PP, PET, PS, PA, PVC) mirrors findings from the Aarin River, Southwestern Nigeria, and Birnin Kebbi rivers (Oladeji *et al.*, 2025; Yahaya *et al.*, 2024). Globally, the concentrations are comparable to those reported in tropical reservoirs in Asia and South America (Maulidah *et al.*, 2025; Ossa-Yepes *et al.*, 2025), with species-specific differences reflecting universal patterns of feeding ecology (Sarijan *et al.*, 2021; Zhu *et al.*, 2022). These comparisons validate that while microplastic contamination is significant in Mairuwa Reservoir, current fish consumption presents low individual health risk, though cumulative effects and water ingestion warrant continued monitoring and preventive measures. The findings contribute to the growing body of evidence that microplastic pollution is a global environmental challenge requiring coordinated international action, including source reduction, improved waste management, and development of effective remediation technologies.

Conclusion

This study provides the first comprehensive assessment of microplastic contamination in commercially important fish species from Mairuwa Reservoir, Northwestern Nigeria, establishing critical baseline data for a previously unstudied freshwater ecosystem.

The findings demonstrate significant microplastic contamination in both *Clarias gariepinus* (298±34 counts/fish) and *Oreochromis niloticus* (253±28 counts/fish), with species-specific accumulation patterns clearly reflecting their contrasting feeding ecologies. Benthic-feeding *C. gariepinus* exhibited higher concentrations of denser polymers (PS: 19.80%, PVC: 17.11%) consistent with sediment exposure, while water-column filtering *O. niloticus* showed greater abundance of lighter polymers (PA: 20.95%, PET: 19.37%) reflecting suspended particle ingestion. FTIR analysis confirmed six polymer types PE, PP, PET, PS, PA, and PVC collectively representing major global plastic production categories, with gill tissues serving as the primary accumulation site (42–45%), followed by liver (25–28%) and edible flesh (18–22%). Monthly variations ($p < 0.05$) indicated seasonal inputs during rainy periods, while spatial uniformity across all nine stations confirmed well-mixed reservoir-wide contamination requiring comprehensive management approaches rather than localized interventions.

The human health risk assessment using EDI, PHI, and CRI frameworks reveals that fish consumption currently poses low risk under existing contamination levels (*C. gariepinus*: CRI = 0.025; *O. niloticus*: CRI = 0.021), suggesting that fish from Mairuwa Reservoir remain relatively safe for human consumption. However, the Polymer Hazard Index values (2.65–2.94) indicate moderate-to-high polymer toxicity across all matrices, primarily driven by the presence of hazardous polymers including PS (toxicity factor = 4) and PVC (toxicity factor = 5), which are associated with carcinogenic monomers (styrene and vinyl chloride). Critically, water ingestion emerged as the dominant exposure pathway with substantially higher risk (CRI = 0.244, High Risk) compared to fish consumption approximately ten times greater reflecting the high daily intake volume (2 L/day), continuous lifelong exposure, and population vulnerability. This finding carries profound public health implications for communities relying on untreated reservoir water, necessitating urgent interventions including household filtration systems, centralized water treatment with microplastic removal capabilities, and regulatory frameworks aligned with emerging WHO guidelines.

The study contributes to the growing body of evidence that microplastic pollution is a global environmental challenge requiring coordinated international action, while simultaneously providing region-specific data essential for evidence-based policy development in Nigeria. The findings support the urgent need for integrated source reduction strategies targeting single-use plastics, improved solid waste management infrastructure, and enhanced agricultural practices to minimize plastic inputs into freshwater ecosystems. Future research should prioritize longitudinal monitoring to track contamination trends, toxicological studies to assess chronic health impacts on vulnerable populations, and development of cost-effective remediation technologies suitable for resource-limited settings. Ultimately, this baseline assessment establishes a foundation for sustainable management of Mairuwa Reservoir, protecting both ecosystem health and the food security of communities dependent on its fisheries, while contributing to the broader understanding of microplastic dynamics in Sub-Saharan African freshwater systems.

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PROTECTIVE EFFECTS OF ACACIA RADDIANA GUM AGAINST URETHANE-INDUCED PULMONARY CARCINOGENESIS IN RATS

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ABSTRACT

Background: Pulmonary carcinogenesis induced by urethane is associated with histopathological alterations and oxidative stress. This study evaluated the protective potential of *Acacia raddiana* gum against urethane-induced lung damage in rats.

Methods: Twenty rats were allocated into four groups: control, urethane-treated, urethane plus *Acacia raddiana* gum (low dose), and urethane plus *Acacia raddiana* gum (high dose). Lung tissues were examined histologically, and oxidative stress markers, including catalase (CAT) and peroxidase (POD), were assessed.

Results: Urethane induced bronchiolar cell hyperproliferation, marked mucin overproduction and significantly increased CAT and POD activities compared with controls. Administration of *Acacia raddiana* gum attenuated mucin overproduction and improved lung histological features. Both doses modulated oxidative stress, with the low dose reducing CAT and POD activities relative to the urethane group and the high dose producing a more pronounced reduction.

Conclusion: *Acacia raddiana* gum exhibits protective effects against urethane-induced pulmonary carcinogenesis by preserving lung histoarchitecture, limiting mucin overproduction, and modulating oxidative stress responses. These findings support its potential as a natural chemopreventive agent against lung carcinogenesis.

COMPUTATIONAL DISCOVERY OF NOVEL C-MET INHIBITORS FOR PROSTATE CANCER THROUGH AN INTEGRATED STRUCTURE- AND LIGAND-BASED DRUG DESIGN APPROACH

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ABSTRACT
Prostate cancer remains one of the leading causes of cancer-related mortality among men, highlighting the urgent need for the development of new targeted therapies. In this study, an integrated computational approach combining 3D-QSAR modeling, scaffold hopping, molecular docking, molecular dynamics (MD) simulations, MM-GBSA calculations, Free Energy Landscape (FEL) analysis, ADMET prediction, and synthetic accessibility analysis was applied to identify novel c-Met kinase inhibitors. A robust CoMSIA-SDHEA model, developed from 45 tetrahydropyrazolo-quinazoline and tetrahydropyrazolo-pyrimidocarbazole derivatives, demonstrated good predictive performance (q^2 = 0.615, r^2 = 0.836, R^2test = 0.878). Electrostatic and hydrophobic interactions were identified as the major factors influencing anticancer activity. Contour map analysis guided the design of 20 new derivatives, among which compound A exhibited the highest predicted activity (pIC50 = 10.856). Molecular docking studies performed on the crystal structure of c-Met kinase (PDB ID: 4XYF) revealed a strong binding affinity for compound A (−11.8 kcal/mol), exceeding that of the most active compound of the initial series, 7q (−10.3 kcal/mol), and the reference drug (−9.9 kcal/mol). MD simulations over 100 ns confirmed the stability of the protein–ligand complex, while MM-GBSA and FEL analyses highlighted stable and energetically favorable interactions. Furthermore, ADMET prediction and synthetic accessibility analysis indicated favorable pharmacokinetic properties and good synthetic feasibility. These findings identify compound A as a promising c-Met inhibitor for the treatment of prostate cancer.
Keywords:Prostate cancer; c-Met kinase; 3D-QSAR; CoMSIA; Molecular docking; Molecular dynamics simulation; MM-GBSA; Free Energy Landscape (FEL); ADMET prediction; Synthetic accessibility analysis.

INTERACTIONS OF SOME PHYSICOCHEMICAL PARAMETERS AND SEDIMENT HEAVY METALS WITH SNAILS SPECIES IN AJIWA RESERVOIR

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ABSTRACT
The aim of this study is to examine some physicochemical parameters, sediment heavy metals concentrations and their interaction with Snails Species in Ajiwa Reservoir, Katsina State. The study was carried out from September to December, 2023. The water and sediment samples were collected twice a month from four (4) sampling stations (A, B, C and D) and analysed for physicochemical parameters such as (pH, temperature, transparency, conductivity, DO and BOD) and heavy metals (Co, Cu, Ni, Mn and Pb) using standard procedures. Snail samples were collected with the aid of D-frame sweep sampler net and identified using standard keys. The physicochemical parameters were found to be within the WHO/NESREA standard limits. The mean of physicochemical parameters of Ajiwa reservoir were pH (7.1031±0.4849), Temperature (22.9281±4.0192), Transparency (12.6093±2.4654), Conductivity (113.9700±10.6330), DO (6.7812±1.0908), and BOD (3.5225±0.8854). The concentration of heavy metals was found in ascending order of Co>Pb>Ni>Mn>Cu. A total of 427 snails from seven (7) different species were observed. There was less abundance of snail species in the month of September (76) and high in October (127). Sampling station C has less abundance of snail species (13) while sampling station B has high abundance (174). The Pearson correlation analysis revealed some snails' species to have positive and negative correlation with Cu, pH and conductivity. The study concludes that there is high abundance of snail species in Ajiwa reservoir particularly in the month of October while less in September. It is recommended that regular assessments of snail species and physicochemical parameters should be conducted to understand ecosystem dynamics.
Keywords: Snail; Heavy metal; Sediment; Abundance; Physicochemical parameters.

GREEN AMBITIONS, INDUSTRIAL PRESSURES: THE TENSION BETWEEN ECONOMIC DEVELOPMENT AND ENVIRONMENTAL PROTECTION IN MOROCCO

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ABSTRACT
Morocco has positioned itself as a regional leader in environmental policy, adopting ambitious frameworks ranging from the 2011 constitutional recognition of environmental rights to the National Sustainable Development Strategy and international climate commitments under the Paris Agreement. The New Development Model (2021) further reinforces this green trajectory, embedding ecological transition as a strategic pillar for the country's 2035 vision. Yet beneath this progressive legislative and institutional architecture lies a persistent tension: the imperative of economic growth, driven by phosphate extraction, industrial expansion, tourism development, and large-scale infrastructure projects, frequently collides with environmental preservation objectives.

This paper examines the structural contradictions within Morocco's environmental policy, focusing on how industrial pressures compromise the effective implementation of preservation strategies. Drawing on an analysis of legal frameworks, institutional mechanisms, and sectoral case studies, it argues that Morocco's environmental governance is characterized by a dual logic—symbolic commitment to sustainability on one hand, and prioritization of short-term economic gains on the other. The study explores specific manifestations of this tension, including weak enforcement of environmental impact assessments, limited judicial sanctions for ecological harm, and the subordination of environmental agencies to economic ministries. It further assesses the role of the New Development Model in addressing—or perpetuating—these contradictions.

The paper concludes by proposing perspectives for reconciling economic development with environmental protection, emphasizing the need for strengthened institutional autonomy, effective criminal and administrative enforcement, and genuine integration of environmental criteria into public and private decision-making. Morocco's experience offers broader lessons for emerging economies navigating the green transition under conditions of structural economic dependence.

Keywords: Morocco, Environmental Policy, New Development Model, Sustainable Development, Economic Development, Environmental Protection

THE RIGHT OF VICTIMS OF MEDICAL MALPRACTICE TO OBTAIN COMPENSATION

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ABSTRACT
Medical malpractice is becoming increasingly common nowadays. More and more patients become victims of medical errors. At the same time, physicians are finding it increasingly difficult to carry out their professional activities, as the number of patients continues to grow. Last but not least, people have also become more aware of their rights and, when they believe that these rights have been violated, they file complaints against healthcare professionals.
In cases of medical malpractice, victims have the possibility of obtaining compensation for medical errors. In some cases, the amounts awarded cover both pecuniary and non-pecuniary damages. The compensation may be substantial, depending on the extent of the harm suffered, the patient's suffering, and other relevant circumstances.
Although medical malpractice cases can be time-consuming, there are many situations in which patients succeed in court and obtain full compensation for the harm suffered. The purpose of such claims is not to send the physician to prison, but rather to enable the patient or their legal successors to recover or cover the expenses incurred in connection with the patient's recovery.
Keywords: medical malpractice; compensation; patient rights; medical errors; damages.

AN AI-DRIVEN MULTILINGUAL SENTIMENT ANALYSIS FRAMEWORK FOR INTELLIGENT HEALTHCARE FEEDBACK AND PATIENT EXPERIENCE ASSESSMENT

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ABSTRACT

Introduction and Purpose

The rapid boom of virtual healthcare systems has generated huge volumes of multilingual patient feedback via social media, online opinions, and healthcare portals. automatically studying those opinions can aid healthcare companies in expertise patient studies and improving carrier high-quality. This examine proposes an AI-pushed multilingual sentiment evaluation framework for classifying and interpreting healthcare-associated textual feedback.

Materials and Methods: The proposed framework integrates herbal Language Processing (NLP), TF-IDF feature illustration, VADER sentiment scoring, multilingual Transformer-based totally contextual embeddings, and gadget gaining knowledge of classifiers. a hybrid interest-based totally structure is employed to combine lexical, contextual, and sentiment features. text preprocessing consists of facts cleansing, normalization, tokenization, and elimination of irrelevant paragraph. The framework classifies healthcare feedback into advantageous, impartial, and poor sentiments.

Results

The incorporated framework demonstrates progressed sentiment classification capability by means of combining conventional system-mastering features with Transformer-based contextual representations. the attention mechanism complements the identification of sentiment-relevant linguistic styles, mainly in multilingual and context-structured healthcare remarks.

Discussion and Conclusion

The proposed technique can help hospitals, healthcare directors, and policymakers in mechanically tracking affected person evaluations and identifying provider-pleasant concerns. The have a look at demonstrates the capability of synthetic Intelligence and NLP for growing wise, statistics-pushed healthcare selection-assist structures.

Keywords: Artificial Intelligence, Sentiment Analysis, Healthcare, Natural Language Processing, Machine Learning, Transformers, Multilingual Analysis, Patient Feedback.

MANAGEMENT OF BIOTIC STRESS IN CROPS WITH PGPR: FUNGAL PATHOGENS, VIRUSES AND PLANT-PARASITIC NEMATODES

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ABSTRACT
Biotic stress caused by fungal pathogens, viruses and plant-parasitic nematodes constrains crop yield, quality and production stability, whereas control strategies relying heavily on pesticides create environmental and economic concerns. This review evaluates the roles of plant growth-promoting rhizobacteria (PGPR) in biotic stress management based on studies conducted in crop plants. PGPR may directly suppress pathogens through antibiosis, lytic enzymes, siderophore production, volatile organic compounds, competition for nutrients and colonization sites, and biofilm formation. They may also strengthen plant immunity by activating jasmonic acid- and ethylene-associated induced systemic resistance and, depending on the interaction, salicylic acid signaling, defense enzymes, phenolic metabolism and antioxidant systems. Bacillus and Pseudomonas species have reduced disease severity in Fusarium wilts, root rots and storage rots; selected treatments have limited viral symptoms and infection; and PGPR applications have decreased galling, egg production and second-stage juveniles of Meloidogyne incognita and other plant-parasitic nematodes. Nevertheless, in vitro antagonism does not consistently predict pot or field performance, and the effectiveness of single strains and consortia varies with the host-pathogen system and environmental conditions. Protection against viruses generally depends on defense priming rather than direct antiviral activity, whereas nematode suppression involves a combination of toxic metabolites, root colonization and reprogramming of host defense metabolism. The contribution of PGPR to sustainable disease management should therefore be evaluated using disease severity, pathogen density, persistence of root colonization, yield and product quality in addition to plant growth. Future research should emphasize multi-location field validation of well-characterized strains, formulation and shelf-life, microbiome interactions, and compatibility with existing integrated pest management practices.
Keywords: biological control, fungal disease, induced systemic resistance, PGPR, plant-parasitic nematode, virus

INTRODUCTION
Throughout their life cycles, plants encounter fungi, bacteria, viruses, viroids, oomycetes, plant-parasitic nematodes, and arthropod pests. When a biotic stress agent establishes in plant tissue, it disrupts nutrient and water use, reduces photosynthetic area, blocks vascular tissues, or redirects cellular metabolism for its own reproduction. The host plant responds through physical barriers, recognition of pathogen-associated molecular patterns, reactive oxygen species, defense hormones, and antimicrobial metabolites. Disease development depends not only on the presence of a pathogen but also on the simultaneous occurrence of a susceptible host, a virulent pathogen, and a conducive environment.
Chemical pesticides can provide rapid and predictable suppression, but their use is constrained by resistance development, effects on non-target organisms, residues, operator safety, and production costs. Persistent control of soilborne pathogens and plant-parasitic nematodes is particularly difficult because inoculum is distributed through the soil profile and may occur in resistant structures. Because no direct curative treatment is available after viral infection, virus management depends mainly on healthy planting material, vector management, and host resistance. Biological control agents are therefore important components of integrated disease management (Majeed et al., 2018; Gupta et al., 2021).
PGPR are bacteria that effectively colonize the root surface or rhizosphere and support plant growth directly or indirectly. Traits such as nitrogen fixation, phosphate solubilization, and siderophore and phytohormone production improve plant nutrition, whereas antagonistic metabolites and defense priming can increase tolerance to biotic stress.

Endospore formation by Bacillus species is advantageous for formulation and storage, while Pseudomonas species are associated with rapid root colonization, siderophore production, and diverse secondary metabolites (Hashem et al., 2019; Meraklı & Memon, 2020).

This review aims to explain the direct and plant-mediated mechanisms of PGPR against fungal pathogens, plant viruses, and plant-parasitic nematodes; compare selected experimental findings; identify limitations in transferring laboratory results to field application; and define research priorities for sustainable biotic stress management.

MAIN TEXT

Direct mechanisms of PGPR in biotic stress management

The direct effects of PGPR on pathogens include antibiosis, parasitism, cell wall-degrading enzymes, competition for iron and other resources, volatile compounds, and occupation of colonization sites. Lipopeptides, phenazines, pyrrolnitrin, 2,4-diacetylphloroglucinol, and various volatile organic compounds produced by Bacillus and Pseudomonas can restrict pathogen germination, hyphal growth, or reproduction. Chitinases, β-1,3-glucanases, proteases, and lipases weaken fungal cell walls, whereas metabolites such as HCN and ammonia may be toxic to some pathogens and nematodes (Shobha & Kumudini, 2012; Hashem et al., 2019).

Siderophores bind Fe^{3+} in the rhizosphere with high affinity and limit pathogen access to iron. Although this mechanism is more effective under iron-limited conditions, it is affected by soil pH, organic matter, and the resident microbiome. Rapid proliferation and biofilm formation on the root surface physically and ecologically occupy infection sites. Strong in vitro antibiosis alone is therefore insufficient; a biological control agent must reach the root, maintain colonization, and remain compatible with the plant.

Dual-culture assays are useful for screening candidates against fungal pathogens, but inhibition measured on culture media does not represent root exudates, soil buffering capacity, or microbial competition. Shobha and Kumudini (2012) showed that Bacillus megaterium isolates produced IAA, ammonia, HCN, and siderophores and suppressed Fusarium oxysporum growth. Such results should not be converted into application recommendations without confirmation based on disease severity, host growth, and field yield.

Induced systemic resistance and defense signaling

Induced systemic resistance (ISR) is a major indirect effect of PGPR. Recognition of beneficial bacteria in the root zone creates a primed state that enables tissues distant from the site of colonization to respond more rapidly and strongly to pathogen attack. ISR is generally associated with jasmonic acid and ethylene signaling, although crosstalk with the salicylic acid pathway varies according to pathogen lifestyle and bacterial strain. ISR and salicylic acid-dominated systemic acquired resistance therefore cannot be separated by strict boundaries in every interaction (Khan et al., 2020).

Following pathogen attack, primed plants may increase the activities of peroxidase, polyphenol oxidase, phenylalanine ammonia-lyase, chitinase, and β-1,3-glucanase more rapidly and restrict infection through the accumulation of lignin, callose, phenolic compounds, and phytoalexins. Changes in antioxidant enzymes are also part of defense. High SOD, CAT, or APX activity alone, however, does not indicate successful protection. Enzyme responses should be evaluated together with H_2O_2, superoxide, MDA, disease severity, and plant growth.

Mufti et al. (2023) reported that combined applications of salicylic acid with Pseudomonas stutzeri or P. putida markedly reduced Fusarium wilt in chickpea and increased defense-related variables, including PAL, PPO, POD, and SOD. These results indicate that PGPR can be integrated with plant activators. Differences among cultivars also show that PGPR effectiveness is not independent of host genotype.

Table 1. Main mechanisms of PGPR in biotic stress management

Mechanism	Biological outcome	Main target
Antibiosis and volatile compounds	Direct suppression of pathogen growth, spore germination, or mobility	Fungi and some nematodes
Lytic enzymes	Degradation of chitin, glucans, proteins, and lipids	Fungal pathogens; nematode eggs/cuticle
Siderophores and competition	Prior use of iron, nutrients, and infection sites	Soilborne pathogens
Root colonization and biofilm formation	Persistence on the root surface and occupation of infection sites	Fungi and nematodes
ISR and defense priming	JA/ET- and SA-associated signaling, defense enzymes, and phenolic metabolism	Fungi, viruses, and nematodes
Support of growth and nutrition	Improved root system, nutrient uptake, and recovery after stress	All biotic stress groups

Note: Outcomes depend on the strain, inoculum density, application time, host genotype, and experimental conditions.

Suppression of fungal diseases by PGPR

Most of the experimental studies examined in this review focus on Fusarium species because these pathogens have broad host ranges, are transmitted through soil and planting material, and are difficult to manage because of persistent chlamydospores. PGPR can suppress wilts and root rots by restricting inoculum development, delaying root infection, reducing vascular colonization, and strengthening plant defense.

A commercial treatment containing Bacillus subtilis reduced the severity of Fusarium wilt caused by Fusarium oxysporum f. sp. lycopersici in tomato, although green-waste compost provided greater protection in the same study (Bilgili & Bilgili, 2023). This comparison shows that PGPR are not the most effective option under all conditions and that organic amendments and mycorrhizal fungi should also be considered in integrated programs. Relationships among disease suppression, plant nutrients, SPAD values, biomass, and rhizosphere activity support the role of soil health in disease outcome.

Bacillus, Burkholderia, Pseudomonas, Flavobacterium, and other strains were tested against Fusarium sambucinum and F. culmorum, which cause dry rot in potato tubers. Some strains limited both in vitro fungal growth and lesion development in tubers (Kotan et al., 2009). This finding indicates that PGPR-related antagonists are not restricted to the rhizosphere of living plants and may also be used in postharvest disease management. Strain identity and toxigenic traits must, however, be verified in detail for food safety.

Bacillus subtilis MAA03 and Pseudomonas fluorescens MAA10 were applied individually and as a mixture against Fusarium graminearum in wheat. The treatments improved germination and plant growth and suppressed root rot (Moussa et al., 2013). Consortia can combine different modes of action, but antagonism, resource competition, or different colonization rates may occur among strains. Mixtures should therefore be assessed through direct analyses of synergy or antagonism rather than by comparison only with the mean response to individual strains.

Fluorescent Pseudomonas isolate EM85 and Bacillus isolates MR-11(2) and MRF were tested as seed and soil treatments against the maize root-rot pathogens Macrophomina phaseolina, Fusarium moniliforme, and F. graminearum. PGPR treatments reduced disease severity and maintained colonization of the root zone (Pal et al., 2001). The combination of the two Bacillus isolates reduced charcoal rot severity by 56%, while MRF and the Tn5::lacZ-marked mutant of EM85 markedly restricted Fusarium root and stalk rots. These findings confirm that PGPR effectiveness should be supported not only by laboratory antagonism but also by the capacity of an isolate to persistently colonize the rhizosphere.

Among Pseudomonas fluorescens isolates evaluated in vitro against Fusarium oxysporum f. sp. lycopersici in tomato, isolate Pf5 showed the greatest antagonistic activity in both the dual-culture assay (58.75% inhibition) and the agar-well assay (80.97% inhibition at 30% concentration) (Vignesh et al., 2021). This result demonstrates substantial variation in antagonistic capacity among isolates of the same species and supports isolate-level screening before field application.

A consortium of multiple PGPR strains from Pseudomonas, Bacillus, Acinetobacter, and Enterobacter, divided into two groups according to biochemical and functional compatibility, was developed against the seed- and soilborne Aspergillus niger, A. flavus, and Fusarium oxysporum disease complex in groundnut. In vitro and pot experiments showed that consortium application increased germination and root growth compared with the control and fertilizer treatments (Syed et al., 2020). The results support the combined use of strains with complementary mechanisms in soilborne disease complexes involving several fungal pathogens.

Combined application of PGPR strains and antagonistic fungi against Fusarium solani root rot in pea reduced disease severity more than individual treatments. Combination treatments also increased defense-related peroxidase and polyphenol oxidase activities, and these changes occurred together with improved plant growth (Sayeed Akhtar & Azam, 2014). This study indicates that bacterial and fungal biological control agents may provide synergistic benefits against soilborne root rots when their compatibility has been verified.

PGPR-mediated protection against plant viruses

Because viruses are obligate parasites that depend on host-cell metabolism, the action of PGPR against viruses differs from direct antagonism against fungal pathogens. The main mechanisms are priming plant defense before infection, slowing systemic spread, and supporting growth under stress. A reduction in symptoms does not necessarily indicate a proportional decrease in virus titer; visual disease severity should be supported by molecular or serological quantification of the virus.

Abdalla et al. (2017) evaluated the protective effects of PGPR against Papaya ringspot virus in squash and Tomato chlorotic spot virus in tomato. Some Bacillus and Pseudomonas treatments reduced disease development and virus accumulation, and efficacy varied with application time and pathosystem. These results suggest that PGPR may provide broad defense priming against viruses with different genome structures and transmission biology, but the response is strain- and host-specific.

Individual and paired applications of Pseudomonas fluorescens, Azotobacter sp., and Bacillus subtilis had different effects on Tobacco mosaic virus disease intensity and plant growth in chili pepper. The P. fluorescens + Azotobacter sp. treatment was effective in restricting disease development and supporting growth (A'yun et al., 2013). A three-strain PGPR combination reportedly improved disease and production variables against Chrysanthemum mild mottle virus in chrysanthemum (Choliq et al., 2020). These studies indicate the potential of consortia, but generalization is limited because experiments were conducted under restricted environmental conditions and virus titer was not quantified by sensitive methods in some studies.

Transient expression of the flagellin protein of Bacillus amyloliquefaciens CRN9 against Groundnut bud necrosis virus (GBNV) in chili pepper was associated with increased expression of epi-aristolochene synthase (EAS1), WRKY33, salicylic acid-related defense genes including NPR1, PAL, PO, and SAR8.2, and jasmonate-responsive PDF and LOX genes. Flagellin-treated plants showed resistance to GBNV and a low virus titer confirmed by qPCR (Rajamanickam & Nakkeeran, 2020). Protection by flagellin alone indicates that PGPR can prime defense against viruses through microbe-associated molecular pattern-triggered immunity (MTI).

Inoculation of wheat with Azospirillum brasilense against Barley yellow dwarf virus (BYDV) not only mitigated virus-induced losses in tiller number and leaf and root dry weight but also restricted population growth of the aphid vector Rhopalosiphum padi (Santos et al., 2025). Reduced infection-related salicylic acid induction in PGPR-associated plants suggests the involvement of systemic resistance in strains that mitigate virus effects. This dual effect at the host and vector levels identifies the PGPR–vector interaction as a separate research area in integrated virus management.

In a broad review of PGPR-mediated protection against plant viral diseases, Sofy et al.

(2019) compiled information on PGPR strains, application methods, and protection levels for many virus–host systems, including Bean common mosaic virus, Bean golden yellow mosaic virus, Cucumber green mottle mosaic virus, Cucumber mosaic virus, Papaya ringspot virus, Pepper mild mottle virus, Potato virus X and Y, Tobacco mosaic virus, Tomato mottle virus, Tomato spotted wilt virus, and Tomato yellow leaf curl virus. Across the studies, protection was largely associated with activation of salicylic acid and/or jasmonic acid–ethylene pathways, consistent with the virus–PGPR interactions evaluated in the present review.

PGPR do not replace healthy seedlings, resistant cultivars, sanitation, removal of infected plants, or vector control in virus management. Their most appropriate role is as a complementary biological treatment that primes defense before infection. For vector-borne viruses, the effects of PGPR on plant volatile profiles, vector behavior, and host suitability should also be investigated.

Suppression of plant-parasitic nematodes by PGPR

Plant-parasitic nematodes, particularly root-knot nematodes, form feeding sites in roots and disrupt water and mineral uptake. Root injury and physiological changes can also facilitate disease complexes with fungal and bacterial pathogens. PGPR can produce metabolites that affect egg hatching and juvenile mobility, colonize the root surface and restrict penetration, and induce host defense (Mhatre et al., 2019; Ansari et al., 2020).

The effects of several commercial microbial fertilizers on Meloidogyne incognita in tomato were compared, and the treatments differed in plant growth, galling, and egg production (Aydınlı & Mennan, 2018). Because viability, density, and colonization ability of the microorganisms in a commercial product determine performance, efficacy should not be inferred from label composition alone.

Khanna et al. (2019) showed that Pseudomonas aeruginosa and Burkholderia gladioli treatments reduced galling and second-stage juvenile numbers in M. incognita-infested tomato. They also decreased H_2O_2, superoxide, and MDA concentrations and modified defense enzymes and phenolic compound accumulation. The metabolomic approach showed that PGPR effects include broad reprogramming of host metabolism rather than nematode mortality alone. However, because P. aeruginosa and some Burkholderia species may be opportunistic human pathogens, safety screening is essential when developing agricultural inoculants.

Meloidogyne, Helicotylenchus, Radopholus, and Pratylenchus are major root pests in banana production. Applications of Pseudomonas fluorescens and Bacillus have been reported to support plant growth and yield by reducing nematode populations and root diseases (Özarslandan et al., 2020). These recommendations should be supported by regional field trials and data on initial and final nematode densities.

Among 27 PGPR strains screened against Meloidogyne incognita in tomato and carrot, five strains—Bacillus firmus T11, Bacillus aryabhattai A08, Paenibacillus barcinonensis A10, Paenibacillus alvei T30, and Bacillus cereus N10w—reduced gall numbers by 81.5–86.0%. In greenhouse trials, P. alvei T30 in carrot and B. aryabhattai A08 in tomato markedly reduced gall and egg-mass indices (Viljoen et al., 2019). Protection was not observed on the untreated half of the root system in a split-root experiment, indicating that efficacy depended more on local, directly toxic secondary metabolites than on distal ISR. This finding supports the distinction between direct toxicity and ISR and explains why effective colonization of the entire root system may provide more reliable protection.

Sidhu (2018) reviewed PGPR species and commercial formulations used for biological control of plant-parasitic nematodes and summarized products based on agents such as Bacillus firmus, B. subtilis, Pseudomonas fluorescens, and Pasteuria penetrans against root-knot and cyst nematodes in different crops. Suppression rates obtained under laboratory and greenhouse conditions were often lower in the field because of formulation stability, shelf life, and variable soil conditions. This assessment is consistent with the laboratory-to-field discrepancy discussed in this review.

Table 2. PGPR–biotic stress interactions in selected experimental studies

Host/target	PGPR or treatment	Main outcome	Reference
Tomato / F. oxysporum f. sp. lycopersici	Bacillus subtilis (commercial product)	Disease severity decreased; compost was more effective.	Bilgili & Bilgili, 2023
Potato / Fusarium dry rot	Bacillus, Burkholderia, Pseudomonas, and other strains	Some strains suppressed in vitro growth and tuber lesions.	Kotan et al., 2009
Wheat / F. graminearum	B. subtilis MAA03 and P. fluorescens MAA10	Germination and growth improved; root rot decreased.	Moussa et al., 2013
Chickpea / Fusarium wilt	P. stutzeri or P. putida + salicylic acid	Disease severity decreased; defense enzymes increased.	Mufti et al., 2023
Squash and tomato / PRSV and TCSV	Bacillus and Pseudomonas strains	Disease and virus accumulation decreased depending on strain and pathosystem.	Abdalla et al., 2017
Chili pepper / TMV	P. fluorescens, Azotobacter sp., B. subtilis, and combinations	Some combinations reduced disease intensity and increased growth.	A'yun et al., 2013
Tomato / M. incognita	P. aeruginosa and B. gladioli	Galling, J2 numbers, and oxidative injury decreased; defense responses increased.	Khanna et al., 2019
Tomato / M. incognita	Commercial microbial fertilizers	Plant growth and nematode reproduction varied among treatments.	Aydınlı & Mennan, 2018

Note: Outcomes depend on the strain, inoculum density, application time, host genotype, and experimental conditions.

Single strains, consortia, and integrated applications

Single-strain applications facilitate mechanism identification and quality control. Consortia can use complementarity in colonization niches, nutrient use, and antimicrobial traits. However, two strains that are effective separately may suppress each other when applied together. Consortium development should examine strain compatibility, mixture ratio, carrier material, storage stability, and temporal dynamics in roots.

Combining PGPR with salicylic acid, compost, arbuscular mycorrhizal fungi, low-risk pesticides, or resistant cultivars may provide more consistent protection. Mufti et al. (2023) demonstrated the relevance of salicylic acid–PGPR integration, while Bilgili and Bilgili (2023) compared bacteria, compost, and mycorrhizal treatments. Comparison only with the best individual treatment is insufficient in integration studies; each component should be tested separately and in combination to distinguish additive effects, synergy, and antagonism.

Application methods include seed coating, root dipping, incorporation into seedling substrate, soil application, and foliar treatment. Seed and seedling treatments provide an early establishment advantage for PGPR that depend on root colonization. However, seed treatments, fertilizers, irrigation-water quality, and pesticide residues in the growing medium may affect bacterial viability. Integrated programs should include compatibility tests between the biological agent and chemical or physical inputs.

Limitations of the evidence and research priorities

The available literature is dominated by Petri-dish assays, controlled-environment experiments, and short-term pot studies. These experiments are necessary for selecting strains and identifying mechanisms, but microbial competition, temperature and moisture fluctuations, inoculum distribution, and agronomic practices in natural soil can change efficacy. A strain should not be assumed to perform equally across pathosystems.

Identification of bacteria only by phenotypic tests, absence of strain-level traceability, and failure to report viable-cell density limit reproducibility in PGPR studies.

Candidates should be genomically identified and assessed for antibiotic-resistance genes, toxins, and opportunistic pathogenicity. In human-associated Pseudomonas and Burkholderia groups, plant growth-promoting traits must not take precedence over biosafety requirements.

Virus studies should measure virus titer by ELISA, RT-qPCR, or another suitable molecular method in addition to symptom scores. Nematode studies should report initial and final populations, reproduction factor, gall and egg counts, while fungal disease studies should include pathogen reisolation or quantitative detection. Across all groups, yield and marketable quality are stronger application criteria than seedling biomass alone.

Multi-location and multi-year trials should address PGPR persistence within the resident microbiome, interaction with host genotype, optimization of dose and application timing, formulation, and shelf life. Reporting confidence intervals and effect sizes together with percentage disease suppression would facilitate comparison among studies and future meta-analyses.

CONCLUSION

PGPR are a multifunctional component of sustainable management programs for fungal diseases, plant viruses, and plant-parasitic nematodes. Their effectiveness depends on the combined action of antagonistic metabolites, root colonization, and defense priming. Bacillus and Pseudomonas are the most frequently studied groups, but efficacy is strain-specific rather than determined only by genus or species.

Direct antagonism and ISR act together against fungal pathogens, whereas protection against viruses is mainly mediated through plant defense. Nematode suppression involves toxic effects on eggs and juveniles, restricted penetration, and reprogramming of defense metabolism. A single measure of PGPR effectiveness is therefore insufficient for all biotic stress agents.

PGPR should not be considered a universal substitute for chemical control. They should be integrated with healthy planting material, resistant cultivars, sanitation, cultural practices, and selective pesticides when required. Development of standardized, safety-verified strains with consistent field performance is a primary requirement for translating laboratory findings into commercial products and farm-level use.

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HEAVY METAL STRESS IN VEGETABLE CROPS AND PGPR-ASSISTED BIOREMEDIATION: PHYSIOLOGICAL MECHANISMS, FOOD SAFETY, AND PRACTICAL APPLICATIONS

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ABSTRACT
The accumulation of heavy metals in agricultural soils restricts vegetable production and threatens food safety through transfer to edible plant parts. This review evaluates the effects of cadmium (Cd), lead (Pb), copper (Cu), zinc (Zn), chromium (Cr), nickel (Ni), cobalt (Co), and mercury (Hg) stress in vegetable crops and the roles of plant growth-promoting rhizobacteria (PGPR) in stress mitigation and bioremediation. After duplicate publications were removed, experimental and review studies were assessed in terms of growth, mineral nutrition, photosynthetic pigments, oxidative stress, antioxidant defense, organ-specific metal distribution, and dietary risk. Heavy metal exposure generally suppresses germination, root elongation, leaf area, and biomass; disrupts nutrient uptake; and increases reactive oxygen species and lipid peroxidation. Antioxidant responses depend on the metal, dose, exposure period, plant organ, and genotype. Studies on tomato, eggplant, radish, garden cress, lettuce, bean, spinach, and Allium species indicate that roots are the main accumulation site for many metals, although transfer to leaves and other edible organs differs among species and genotypes. PGPR can modify metal bioavailability and plant stress responses through exopolysaccharide production, biosorption, bioaccumulation, precipitation, redox transformation, siderophore and organic acid production, phosphate solubilization, indole-3-acetic acid synthesis, and 1-aminocyclopropane-1-carboxylate deaminase activity. However, PGPR may immobilize metals and reduce their entry into edible tissues or mobilize them and promote phytoextraction. Safe vegetable production should therefore be distinguished from remediation-oriented cultivation. Performance should be assessed using bioavailable soil metal, root-to-shoot transfer, metal concentration in edible organs, health-risk indices, and biomass. Field studies should examine interactions among metal type, PGPR strain, crop genotype or rootstock, mixed contamination, growing environment, and microbial persistence.
Keywords: bioremediation, food safety, heavy metal, oxidative stress, PGPR, vegetable crop

INTRODUCTION
Industrial activity, mining, phosphate fertilizers, pesticides, sewage sludge, wastewater irrigation, and atmospheric deposition are major anthropogenic sources of heavy metals in agricultural soils. Cd, Pb, Hg, and As are not required for plant growth, whereas Cu, Zn, Fe, Mn, Ni, and Co have metabolic functions at low concentrations but become toxic at high concentrations. Because heavy metals are not biodegradable, they persist in soil. Their mobility is controlled by pH, organic matter, clay minerals, redox potential, and chemical speciation (Gulzar & Mazumder, 2022; Gupta et al., 2024; Zulfiqar et al., 2023).

Vegetable crops require particular attention in relation to heavy metal contamination because they have short production cycles, are often grown under intensive fertilization and irrigation, have edible leaves, roots, stems, fruits, or bulbs, and include species with high element accumulation capacity. Metal retention in roots may protect shoots, but it creates a direct dietary risk in root vegetables. High transpiration and rapid biomass production may also increase metal accumulation in leafy vegetables. Huang et al. (2021) reported that Cd accumulation was greater than Cu accumulation in five vegetables grown in contaminated soil and that the hazard index for Cd exceeded 1 under some consumption scenarios. The absence of visible toxicity therefore does not indicate that a crop is safe for consumption. Physical and chemical remediation methods can act rapidly, but they may require high costs and energy inputs, degrade soil properties, and generate secondary waste. Bioremediation based on plants and microorganisms offers a lower-cost approach with less environmental disturbance.

PGPR can promote plant growth and modify metal speciation, mobility, and root-to-shoot transfer in the rhizosphere. PGPR-mediated metal immobilization and mobilization, however, serve different production goals. This review examines the physiological and biochemical effects of heavy metal stress in vegetable crops, evaluates PGPR mechanisms in relation to safe crop production and phytoremediation, and identifies research priorities.

MAIN TEXT

Effects of heavy metals on plant growth and mineral nutrition

Delayed germination, inhibited root elongation, and reduced seedling biomass are early symptoms of heavy metal toxicity. Roots are the first organs exposed to metal ions; therefore, cell division and elongation are often affected before shoot growth. Cd and Pb reduced germination and root and shoot growth in mustard, while Cd induced a stronger antioxidant response (Heidari & Sarani, 2011). Based on root elongation in Sinapis alba seedlings, toxicity followed the order Cu > Cd > Fe ≈ Zn > Pb; all metals except Fe accumulated more in roots than in shoots (Fargašová, 2001). Complete inhibition of root formation at high Cd, Co, Ni, and Cu concentrations in garlic confirms that root development is a sensitive indicator of metal toxicity (Baktemur, 2023).

Heavy metals disrupt mineral balance by competing with essential nutrients for transporters and binding sites. In tomato, increasing Cd reduced the uptake of P, Ca, K, Mg, and Fe, whereas Pb reduced P, Ca, Zn, and Mn uptake (Aksu & Yıldız, 2007). Cd altered the distribution of Fe, Zn, Mn, and Cu in radish (El-Beltagi et al., 2010). Increasing Cd raised plant Cd concentration and reduced Fe concentration in cotton (Karanlık et al., 2013). Chlorosis and growth inhibition under heavy metal stress are therefore associated with both direct toxicity and secondary nutrient deficiencies.

Dose-response relationships are not always linear. Jiang et al. (2001) found that 10^{-6}-10^{-5} M Cd stimulated root elongation in garlic, whereas 10^{-3}-10^{-2} M Cd reduced growth. Low-dose stimulation may be described as hormesis, but it should not be considered beneficial without assessing tissue metal accumulation and long-term food safety. Similarly, essential micronutrients may promote growth at low concentrations but cause toxicity above a threshold.

Photosynthetic processes, water relations, and oxidative stress

Cd, Pb, Cu, and other metals can affect chlorophyll biosynthesis, photosystem integrity, stomatal conductance, and carbon assimilation. Cd reduced leaf area, chlorophyll, and carotenoid concentrations in radish, with a larger decline in chlorophyll b than in chlorophyll a (El-Beltagi et al., 2010). Cd, Zn, Cu, and Pb inhibited chlorophyll b in mustard (Fargašová, 2001), while increasing Cd reduced chlorophyll a, chlorophyll b, and total chlorophyll in cotton (Karanlık et al., 2013). In a garlic-perennial ryegrass intercropping study, Cr reduced transpiration by 69.24%, whereas the decrease in photosystem II efficiency was smaller (Ali et al., 2024). Pigment concentration, gas exchange, and chlorophyll fluorescence should therefore be evaluated together rather than using a single photosynthetic variable.

Heavy metals may increase the formation of superoxide radicals, hydrogen peroxide, and hydroxyl radicals by disrupting electron transport and antioxidant balance, whether or not they participate directly in redox reactions. These reactive oxygen species damage proteins, nucleic acids, pigments, and membrane lipids. Malondialdehyde (MDA) is commonly used as an indicator of lipid peroxidation, whereas electrolyte leakage indicates loss of membrane integrity. A mixture of Cu, Cd, Pb, and Zn reduced growth and increased MDA and the activities of SOD, CAT, APX, and GR in eggplant (Kıran et al., 2015). A similar metal mixture increased MDA, SOD, and GR in lettuce, while humic acid partly reduced growth injury (Özkay et al., 2016).

An increase in antioxidant enzyme activity does not always indicate stress mitigation. Cd and Zn increased lipid peroxidation in bean, decreased CAT activity in roots and leaves, and increased APX and GR activities in leaves (Chaoui et al., 1997). In cotton, CAT increased, whereas APX increased at a low Cd dose and decreased at higher doses (Karanlık et al., 2013). High Pb increased MDA, CAT, and POD in garlic roots (Liu et al., 2009). These findings show that enzyme responses depend on organ, dose, and exposure period. PGPR performance should therefore be interpreted using MDA, H_2O_2, electrolyte leakage, pigments, and biomass in addition to enzyme activity.

Metal accumulation, organ-specific transfer, and genotype effects in vegetables

Metal uptake and translocation differ among plant species, cultivars, and organs. Allium species are often used in metal-binding and tolerance studies because of their metabolism of sulfur-containing compounds, phytochelatins, and metallothioneins. Garlic roots accumulated about 1,826 times more Cd than the control at 10^{-2} M Cd, while transfer to bulbs and shoots remained low (Jiang et al., 2001). Pb also accumulated mainly in garlic roots, with limited transfer to edible bulbs and shoots (Liu et al., 2009). Under hydroponic conditions, most Cd, Co, Cu, Ni, Pb, and Zn was retained in the roots of garlic, onion, leek, and chive, with differences among species and onion cultivars (Soudek et al., 2009). A subsequent garlic study showed that hydroponic heavy metal exposure affected not only organ-specific accumulation but also growth and physiological stress indicators, demonstrating that metal uptake and stress responses should be assessed together (Soudek et al., 2011).

High root accumulation may be useful in safe crop production when it limits transfer to edible organs, but it may be unfavorable for phytoextraction because less metal is removed in harvested shoots. Root retention also does not ensure safety in root or bulb vegetables. In garlic grown in Ethiopia, most elements were present at higher concentrations in leaves than in bulbs, while Pb and Cd remained within the limits considered in the study (Tegegne & Mengiste, 2016). Pb and Cd concentrations in shallot and garlic samples from Thailand were below national and international limits (Phuengphai et al., 2022). Field surveys complement controlled stress experiments but do not provide direct evidence on metal source or dose-response mechanisms.

Genotypic variation is a useful resource for improving heavy metal tolerance. The Rio Grande tomato cultivar was more tolerant to Cd (Aksu & Yıldız, 2007), and tolerant eggplant genotypes originating from Burdur performed better than sensitive genotypes under a heavy metal mixture (Kıran et al., 2015). Under Pb stress, Köksal F1 and AGR-703 rootstocks and breeding lines from Mardin-Kızıltepe and Burdur showed smaller growth reductions (Topal et al., 2017). Rootstocks may be combined with PGPR to restrict root-to-shoot metal transfer.

Table 1. Main effects of heavy metal stress in selected vegetable and Allium studies

Crop	Metal/treatment	Main finding	Reference
Tomato	Cd and Pb	Dry matter decreased; Cd reduced P, Ca, K, Mg, and Fe uptake, while Pb reduced P, Ca, Zn, and Mn uptake.	Aksu & Yıldız, 2007
Eggplant	Cu + Cd + Pb + Zn	Biomass and leaf area decreased; MDA and antioxidant enzyme activities increased; genotypic differences were detected.	Kıran et al., 2015
Lettuce	Cu + Cd + Pb + Zn	MDA, SOD, and GR increased; humic acid reduced growth injury.	Özkay et al., 2016
Radish	Cd	Leaf area and pigments decreased; Cd accumulated mainly in roots; CAT, GST, and POD increased.	El-Beltagi et al., 2010
Garlic	Cd	Low Cd stimulated root growth, while high Cd inhibited growth; Cd accumulated mainly in roots.	Jiang et al., 2001
Garlic	Pb	Root and shoot growth decreased; Pb accumulated in roots; MDA and some enzyme activities increased.	Liu et al., 2009
Allium species	Cd, Co, Cu, Ni, Pb, Zn	Metals accumulated mainly in roots; transfer to bulbs and leaves differed among species and cultivars.	Soudek et al., 2009
Spinach	Cd + O. intermedium BB12	Germination, chlorophyll status, and biomass improved; Cd uptake and translocation decreased.	Renu et al., 2022

Note: The responses listed in the table depend on metal type, dose, growing medium, plant genotype, and exposure period.

Mechanisms by which PGPR mitigate heavy metal stress

Metal-tolerant PGPR can survive in contaminated rhizospheres while modifying plant growth and metal behavior. Carboxyl, hydroxyl, amino, phosphate, and sulfhydryl groups in cell walls and exopolysaccharides can bind cationic metals. In addition to metabolism-independent biosorption, active cellular uptake, sequestration, efflux pumps, precipitation, and biomineralization may occur (Bozanta & Ökmen, 2011; Gupta et al., 2024; Sahoo et al., 2024). Cd cannot be degraded by microorganisms; microbial activity can only change its chemical form, mobility, bioavailability, or location.

Siderophores facilitate Fe acquisition and may form complexes with Cd, Pb, Zn, Ni, and other metals. Organic acids can lower rhizosphere pH, solubilize metals, and promote phytoextraction. In contrast, metal-phosphate precipitation following phosphate solubilization or an increase in pH can support immobilization. Strains classified under the general term PGPR may therefore change metal uptake in opposite directions. Sahoo et al. (2024) considered PGPR-assisted phytoextraction, phytostabilization, and phytovolatilization as separate processes, while Gupta et al. (2024) described biosorption, bioaccumulation, siderophore production, phosphate solubilization, and ACC deaminase activity.

IAA and other phytohormones can increase root branching and surface area. ACC deaminase degrades ACC, the precursor of ethylene, and may maintain root growth under stress. Nitrogen fixation and P solubilization support mineral nutrition, while regulation of antioxidant defense can limit ROS-induced injury. PGPR bioformulations altered growth, chlorophyll concentration, and SOD, CAT, and POD activities in garlic under non-stress conditions (Esringü et al., 2016). Although this study did not include heavy metals, it confirms that garlic responds physiologically to PGPR and provides mechanistic rather than direct evidence for metal-stressed plants.

A key direct study in vegetables examined the Cd-resistant strain Ochrobactrum intermedium BB12 in spinach. BB12 showed Cd biosorption through nitrogen-containing groups on its EPS. Under 50 mg kg^{-1} Cd, it increased shoot fresh weight by 28.33% and root fresh weight by 72.60%, improved chlorophyll status, and reduced Cd uptake and translocation (Renu et al., 2022). The combined application of Lactobacillus plantarum and red mud increased garlic biomass by 33.2%, reduced available soil Cd by up to 59.4%, and reduced plant Cd by up to 44.3% (Zhu et al., 2021). However, L. plantarum is not a typical root-derived PGPR, and its effect was evaluated in combination with red mud. Cellulosimicrobium cellulans KUCr3 reportedly reduced Cr accumulation by 57% in roots and 37% in shoots of pepper (Sahoo et al., 2024). Such results are relevant to safe crop production, but food safety cannot be confirmed without measuring metal concentrations in edible fruits. Direct vegetable × heavy metal × PGPR experiments remain less common than studies on cereals, energy crops, and hyperaccumulators. Evidence from other plant groups should therefore be applied to vegetables with a clear statement of the level of evidence.

Table 2. Main PGPR mechanisms under heavy metal stress and their production outcomes

Mechanism	Effect on metal	Plant outcome	Appropriate objective
Biosorption and EPS	Metals bind to the cell surface, which may reduce mobility.	Toxicity in the root zone and transfer to shoots may decrease.	Stabilization / safe production
Bioaccumulation and sequestration	Metals are retained within microbial cells.	Free-ion activity may decrease.	Stabilization
Organic acids and acidification	Metal solubility and bioavailability may increase.	Plant uptake and removal may increase, but toxicity risk may also rise.	Extraction

Mechanism	Effect on metal	Plant outcome	Appropriate objective
Siderophores	Fe nutrition and metal complexation are modified.	Chlorophyll status and growth may improve; metal uptake may increase or decrease depending on the strain.	Strain-specific
Phosphate solubilization/precipitation	Metal-phosphate formation may promote immobilization.	Metal transfer may decrease while P nutrition improves.	Safe production
IAA and ACC deaminase	These mechanisms act on stress signaling rather than directly on metal speciation.	Root development, biomass, and stress tolerance increase.	Both
Regulation of antioxidant systems	Secondary injury caused by ROS decreases.	MDA, H_2O_2, and membrane injury may decrease.	Stress tolerance

Note: The responses listed in the table depend on metal type, dose, growing medium, plant genotype, and exposure period.

Distinguishing phytoremediation from safe vegetable production

The aim of phytoextraction is to take up metals through roots, accumulate them in harvestable shoots, and remove the biomass from the site. In food production, the aim is to maintain yield while keeping metal concentrations in edible organs below permitted limits. High shoot metal accumulation in an edible vegetable may be successful for phytoremediation but unacceptable for food safety. Gulzar and Mazumder (2022) emphasized the risk of introducing metals into the food chain when edible crops are used for phytoextraction.

Metal retention in roots of Allium species indicates a tendency toward phytostabilization. In onion, phytoextraction was considered suitable at a low Cu dose, whereas phytostabilization was more appropriate at higher doses (Gedik, 2022). Garlic-perennial ryegrass intercropping increased biomass and showed phytoremediation potential in Cd-, Cr-, and Pb-contaminated areas (Ali et al., 2024). When crops are intended for consumption, metal concentrations in edible organs and daily intake risk should take priority over total metal removal.

Performance criteria in PGPR studies should be defined according to the intended use. For safe production, key measures include biomass or yield, metal concentration in edible organs, transfer factor, estimated daily intake, and hazard index. For phytoextraction, total shoot metal removal, bioconcentration factor, translocation factor, and harvestable biomass are required. For phytostabilization, the bioavailable soil fraction, leaching, root accumulation, and soil microbial activity are relevant.

Growing medium, organic amendments, and methodological comparability

The nominal dose applied in a heavy metal experiment is not equal to the bioavailable dose received by the plant. Vázquez and Carpena-Ruiz (2005) showed that the biologically equivalent Cd dose in a perlite system was about 14 times lower than in hydroponics and that desorbed Cd was about one-twelfth of the applied dose. Identical numerical doses in perlite, peat, soil, and hydroponic systems are therefore not comparable. Studies should report dissolved or extractable metal fractions, pH, electrical conductivity, organic matter, and cation exchange capacity in addition to total metal.

Organic amendments may support or mask PGPR effects. Peat moss reduced Pb mobility in contaminated soil, with a stronger effect at higher amendment rates (Lee et al., 2013). Humic acid reduced Cd injury in garden cress and significantly decreased Cd uptake at the high application rate (Alım, 2020).

In lettuce exposed to a metal mixture, 4 L da^{-1} humic acid limited growth reduction (Özkay et al., 2016). Because these materials can bind metal ions, amendment-only controls are required in PGPR + amendment studies.

Heavy metals affect rhizosphere microorganisms and soil enzymes as well as plants. In growing substrates artificially contaminated with V, Ni, Cd, Pb, Cu, and Cr, microbial respiration and enzymes involved in C, N, S, and P cycling decreased, and microbial energy-use efficiency was impaired (Papa & Alvarez-Romero, 2023). In vitro metal tolerance therefore does not ensure root colonization or activity in soil. Persistence in the rhizosphere, competition, and microbiome shifts should be measured.

Limitations and research priorities for field application

Much of the available literature is based on hydroponic systems, Petri dish assays, or short-term pot experiments. These systems are useful for explaining mechanisms, but metal aging and complexation, interactions among multiple metals, climate, irrigation, and the resident microbiome may alter results in field soil. Some studies use metal doses well above environmental concentrations. Such doses help reveal stress mechanisms but limit the development of field recommendations.

PGPR strain selection should not rely only on IAA production, phosphate solubilization, and siderophore assays. Tolerance to the target metal or metal mixture, biosorption capacity, ACC deaminase and EPS production, root colonization, environmental safety, and antibiotic resistance genes should also be assessed. Because some genera include opportunistic pathogens, taxonomic identity should be confirmed at strain level using genomic methods. Comparisons between single strains and consortia and assessment of carrier formulation and shelf life are also required.

Vegetable breeding and microbial inoculant development should not be conducted independently. Genotypic differences in tomato and eggplant and the Pb tolerance of eggplant rootstocks indicate that PGPR response may depend on genotype. Future experiments should use a factorial metal × PGPR × genotype or rootstock design with adequate biological replication, a PGPR control without metal, and a metal control without PGPR. Effect sizes and confidence intervals should be reported in addition to multiple-comparison tests.

Field validation should include at least two environments or seasons; total and bioavailable soil metal fractions; metal concentrations in roots, leaves, stems, and fruits or bulbs; yield and quality; MDA, H_2O_2, antioxidant enzymes; and microbial colonization. When food production is the objective, national and international maximum limits should be expressed on a fresh-weight basis, and health risks should be calculated for child and adult exposure scenarios. Management of metal-enriched biomass after harvest is also part of the phytoremediation process.

CONCLUSION

Heavy metal contamination in vegetable production is a multidimensional problem because it causes growth and yield losses, transfer to edible organs, and risks to human health. The studies reviewed indicate that Cd strongly affects root development, mineral nutrition, and photosynthetic pigments in many vegetable species. The effects of Pb, Cu, Zn, Ni, Co, Cr, and Hg depend on metal dose, chemical form, and plant genotype. MDA, H_2O_2, and electrolyte leakage indicate oxidative injury, while antioxidant enzymes indicate defense responses; none should be interpreted as a positive or negative outcome when considered alone.

PGPR provide complementary mechanisms for managing heavy metal stress, including biosorption, EPS production, precipitation, siderophore and organic acid production, phosphate solubilization, IAA synthesis, ACC deaminase activity, and regulation of antioxidant systems. PGPR may either decrease or increase metal mobility. Inoculants should therefore be selected according to the primary goal: safe crop production, phytostabilization, or phytoextraction.

Direct vegetable-heavy metal-PGPR studies are promising but limited in number and field validation. Future studies should address single- and mixed-metal contamination at environmentally relevant concentrations and test interactions among plant genotype or rootstock, PGPR strain or consortium, organic amendment, and growing medium. Performance should be evaluated using bioavailable soil metal, root-to-shoot transfer, metal concentration in edible organs, total metal removal, microbial persistence, and health risk in addition to plant biomass. This approach can support the transfer of PGPR technology from controlled experiments to safe and sustainable vegetable production.

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EFFECTS OF PGPR APPLICATIONS ON PLANT GROWTH, YIELD, AND STRESS TOLERANCE IN BRASSICA NAPUS L. CULTIVATION

BRASSICA NAPUS L. YETİŞTİRİCİLİĞİNDE PGPR UYGULAMALARININ BİTKİ GELİŞİMİ, VERİM VE STRES TOLERANSI ÜZERİNE ETKİLERİ

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ABSTRACT

Brassica napus L. (rapeseed/canola) is one of the important oilseed crops due to its high seed and oil yield and its capacity to adapt to diverse environmental conditions. However, drought, salinity, high temperature, heavy metal toxicity, and nutrient deficiencies can limit plant growth, photosynthetic activity, mineral nutrition, yield, and seed quality. This review evaluates the potential of plant growth-promoting rhizobacteria (PGPR) in *B. napus* cultivation, with particular emphasis on root colonization and underlying mechanisms of action, application methods, interactions with mineral fertilizers, plant growth and nutrient acquisition, yield and seed characteristics, abiotic stress tolerance, disease management, microbial consortia, and performance under field conditions.

Current studies indicate that certain PGPR strains and consortia can positively affect root and shoot development, photosynthetic traits, nutrient uptake, biomass production, selected yield components, and stress-related physiological and biochemical responses in *B. napus*. However, the magnitude and reproducibility of these responses vary depending on factors such as bacterial strain, plant genotype, soil properties, environmental conditions, inoculum density, application method, and the indigenous rhizosphere microbiota. In particular, the beneficial effects reported under greenhouse and controlled conditions appear to be more variable under field conditions. Therefore, rather than being considered direct substitutes for mineral fertilizers or other essential crop management practices, PGPRs should more realistically be regarded as complementary biological inputs that can be integrated with appropriate fertilization, irrigation, and disease management strategies. Future research should focus on multi-location and long-term field trials, identification of strain–genotype compatibility, and standardization of inoculum, formulation, and application methods.

Keywords: Canola, plant growth-promoting rhizobacteria, PGPR, nutrient use efficiency, yield, stress tolerance, sustainable agriculture

ÖZET

Brassica napus L. (kanola/kolza), yüksek tohum ve yağ verimi ve farklı çevre koşullarına uyum kapasitesi nedeniyle önemli yağ bitkilerinden biridir. Bununla birlikte kuraklık, tuzluluk, yüksek sıcaklık, ağır metal toksisitesi ve besin elementi yetersizlikleri bitki gelişimini, fotosentetik aktiviteyi, mineral beslenmeyi, verimi ve tohum kalitesini sınırlandırabilmektedir. Bu derlemede, bitki gelişimini teşvik eden rizobakterilerin (plant growth-promoting rhizobacteria; PGPR) *B. napus* yetiştiriciliğindeki potansiyeli; kök kolonizasyonu ve temel etki mekanizmaları, uygulama yöntemleri, mineral gübrelerle etkileşim, bitki gelişimi ve besin elementi kullanımı, verim ve tohum özellikleri, abiyotik stres toleransı, hastalık yönetimi, mikrobiyal konsorsiyumlar ve tarla koşullarındaki etkinlik açısından değerlendirilmiştir.Mevcut çalışmalar, bazı PGPR suşları ve konsorsiyumlarının *B. napus*'ta kök ve sürgün gelişimi, fotosentetik özellikler, besin elementi alımı, biyokütle, bazı verim bileşenleri ve stresle ilişkili fizyolojik ve biyokimyasal yanıtlar üzerinde olumlu etkiler oluşturabildiğini göstermektedir. Bununla birlikte yanıtların büyüklüğü ve tekrarlanabilirliği; bakteri suşu, bitki genotipi, toprak özellikleri, çevresel koşullar, inokulum yoğunluğu, uygulama yöntemi ve rizosfer mikrobiyotası gibi faktörlere bağlı olarak değişmektedir. Özellikle sera ve kontrollü koşullarda bildirilen olumlu sonuçların tarla koşullarında daha değişken olduğu görülmektedir. Bu nedenle PGPR'lerin mineral gübrelerin veya diğer temel yetiştiricilik uygulamalarının doğrudan alternatifi olmaktan ziyade, uygun gübreleme, sulama ve hastalık yönetimiyle birlikte kullanılabilecek tamamlayıcı biyolojik girdiler olarak değerlendirilmesi daha gerçekçi görünmektedir.

Gelecekte çok lokasyonlu ve uzun süreli tarla çalışmalarına, suş–genotip uyumluluğunun belirlenmesine ve inokulum, formülasyon ve uygulama yöntemlerinin standardizasyonuna ihtiyaç bulunmaktadır.

Anahtar Kelimeler: Kanola, bitki gelişimini teşvik eden rizobakteriler, PGPR, besin kullanım etkinliği, verim, stres toleransı, sürdürülebilir tarım

1. INTRODUCTION

Brassica napus L. (rapeseed/canola) is an important oilseed crop because of its high yield potential, high oil content, and adaptation to a wide range of environmental conditions (Kayaçetin, 2023; Farhat et al., 2023; Jalal et al., 2023). However, the realization of the yield potential of the crop depends not only on genotype but also on the appropriate management of water, nutrients, and environmental conditions (Jalal et al., 2023; Farhat et al., 2023; Shah et al., 2021; Zandalinas et al., 2021). Abiotic stresses such as drought, salinity, and high temperature can limit plant growth and yield by altering water relations, photosynthetic activity, ion homeostasis, and oxidative metabolism (Shah et al., 2021; Zandalinas et al., 2021).

The ability of rapeseed to produce high biomass and seed yield depends on the balanced and efficient uptake of macro- and micronutrients. In addition to nitrogen, phosphorus, and potassium, adequate availability of zinc, boron, and other micronutrients is important for vegetative growth and reproductive development. However, plant nutrient acquisition is determined not only by the total amount of an element in the soil, but also by its availability for plant uptake, the capacity of the root system to access nutrients, and microbial processes occurring in the rhizosphere. Plant growth-promoting rhizobacteria (PGPR) can contribute to plant nutrition through mechanisms such as phosphate solubilization, siderophore production, stimulation of root development, and enhancement of nutrient availability to plants (Bashir et al., 2024; Farhat et al., 2023; Jalal et al., 2023). Indeed, zinc-solubilizing PGPR have been reported to enhance nutrient uptake in rapeseed and consequently exert positive effects on plant growth, yield, and oil content (Jalal-Ud-Din et al., 2024). Similarly, the composition of microbial communities in the rhizosphere and plant–microorganism interactions can influence nutrient utilization in the root zone and the nutritional status of plants (Liu et al., 2021).

Plant growth-promoting rhizobacteria (PGPR) have emerged as important biological inputs for sustainable crop production. By colonizing plant roots or the surrounding rhizosphere, PGPR can influence plant performance through several mechanisms, including enhancing nutrient availability, biological nitrogen fixation in some strains, production of phytohormones and siderophores, ACC deaminase activity, and stimulation of plant defense responses (Bhattacharyya & Jha, 2012; Santoyo et al., 2021).

Nevertheless, PGPR efficacy is a more complex process than the demonstration of a single bacterial trait under laboratory conditions. Attachment to the root surface, utilization of root exudates, proliferation in the rhizosphere, and the ability to compete with indigenous microbial communities are among the major factors determining successful colonization (Lopes et al., 2016; Santoyo et al., 2021; Liu et al., 2024). Therefore, the identification of traits such as phosphate solubilization, IAA production, or siderophore production alone does not necessarily guarantee a successful plant growth response under field conditions.

Studies conducted on *B. napus* have demonstrated that different PGPR strains may possess traits such as phosphorus and zinc solubilization, nitrogen fixation, phytohormone production, and ACC deaminase activity. For example, a study conducted with zinc-solubilizing bacteria reported that certain isolates positively affected nutrient acquisition, plant growth, yield, and oil-related traits in rapeseed (Jalal-Ud-Din et al., 2024). In contrast, the increase in boron uptake observed following the application of *Bacillus pumilus* was accompanied by growth suppression under certain conditions, highlighting the need to evaluate PGPR effects within the context of nutrient balance (Masood et al., 2019).

The combined use of PGPR with mineral fertilizers is also an important area of research. Some studies have shown that PGPR applications can support rapeseed growth under reduced nitrogen fertilization (Naseri et al., 2013). However, current evidence supports PGPR not as a general and direct replacement for mineral fertilizers, but rather as a complementary approach capable of improving nutrient use efficiency.

Different PGPR strains have also been associated with positive physiological and biochemical responses in rapeseed under abiotic stresses. Improvements in root development, photosynthetic activity, antioxidant defense, and mineral nutrition have been reported under drought and salinity conditions (Saghafi et al., 2019; Abdel Latef et al., 2021; Rossi et al., 2021; Tanveer et al., 2023; Ajijah et al., 2024). However, differences in experimental conditions and bacterial strains among these studies make direct generalization of the findings difficult.

The aim of this review is to comprehensively evaluate the current evidence on the use of PGPR in *B. napus* production; to examine the major mechanisms of PGPR action and application methods; to assess their interactions with mineral fertilizers; to evaluate their effects on plant growth and yield; to discuss their potential under abiotic stress conditions and their role in disease management; and, particularly, to identify their effectiveness and limitations under field conditions.

2. KEY MECHANISMS OF PGPR ACTION IN RAPESEED

PGPR can promote plant performance through multiple and interconnected mechanisms that operate at the plant–microbe–soil interface. In rapeseed, these mechanisms include successful root colonization, modulation of plant hormone signaling, improvement of nutrient availability, mitigation of stress-induced ethylene accumulation, and enhanced iron acquisition. The relative contribution of each mechanism may vary according to bacterial strain, plant genotype, soil conditions, and environmental stress.

2.1. Root Colonization

A fundamental prerequisite for PGPR efficacy is the ability of the bacterium to reach the root zone and maintain its viability there for a sufficient period. Organic compounds released by roots influence the formation of microbial communities in the rhizosphere, while bacterial attachment to the root surface and the ability to compete with indigenous microorganisms determine colonization success (Santoyo et al., 2021; Liu et al., 2024). The development of microbial communities in the rapeseed rhizosphere may vary depending on plant developmental stage, indicating that plant growth stage should also be considered when selecting PGPR strains (Wang et al., 2024). Therefore, successful PGPR application depends not only on the functional traits of the bacterium but also on the interactions among the bacterium, plant, and rhizosphere.

2.2. Phytohormone Production

Bacterial indole-3-acetic acid (IAA) production can support water and nutrient uptake by affecting lateral root formation and root architecture. However, a substantial proportion of the evidence concerning this mechanism comes from the broader *Brassica* literature. For example, IAA production and plant growth-promoting properties of *Pseudomonas putida* UB1 have been demonstrated in *Brassica nigra* (Bharucha et al., 2013).

2.3. Enhancement of Nutrient Availability

PGPR can increase the availability of phosphorus and certain micronutrients for plant uptake. Phosphate-solubilizing bacteria may enhance the availability of insoluble phosphorus forms through the production of organic acids and phosphatase activity (Sarmah & Sarma, 2023; Bashir et al., 2024). In rapeseed, zinc solubilization has also emerged as an important research area. Jalal-Ud-Din et al. (2024) reported that zinc-solubilizing PGPR strains could promote nutrient acquisition and plant growth in rapeseed. However, increased nutrient uptake does not always result in a positive agronomic outcome. The example of boron demonstrates that increased boron uptake following *B. pumilus* application may be accompanied by growth suppression under certain conditions, indicating that PGPR effects should be evaluated in relation to plant nutrient requirements and the balance among different elements (Masood et al., 2019).

2.4. ACC Deaminase Activity

ACC deaminase-producing bacteria can contribute to the maintenance of root and shoot growth under stress conditions by limiting excessive ethylene accumulation in plants (Chandwani & Amaresan, 2022; Shahid et al., 2023). Halotolerant *Rhizobium* strains possessing ACC deaminase activity have been reported to promote growth in *B. napus* seedlings under salinity stress (Saghafi et al., 2019).

This finding indicates that ACC deaminase activity may represent one of the mechanisms contributing to stress tolerance in rapeseed.

2.5. Siderophore Production

Siderophores are compounds that enable bacteria to bind iron and may influence iron competition in the rhizosphere and, in some cases, pathogen access to iron (Kramer et al., 2020; Timofeeva et al., 2022). However, the detection of siderophore production under laboratory conditions does not, by itself, indicate greater yield or iron uptake in rapeseed. Therefore, siderophore production should be considered one of the potential functional traits of PGPR and evaluated together with other plant and rhizosphere responses.

3.PGPR APPLICATION METHODS AND INTERACTIONS WITH MINERAL FERTILIZERS

The success of PGPR application depends not only on bacterial strain characteristics but also on the application method, timing, inoculum density, and formulation (Bashan et al., 2014; Santoyo et al., 2021). In *B. napus*, direct evidence is available particularly for seed inoculation/coating, root–rhizosphere, and soil applications (Lally et al., 2017; Farhat et al., 2023; Dobrzyński et al., 2024a, 2024b). Seed application is a practical method because it enables bacteria to reach the root zone during the early stages of plant development. In root–rhizosphere and soil applications, efficacy may be influenced by environmental and microbial factors such as soil moisture, pH, temperature, and indigenous microbiota (Santoyo et al., 2021). The effects of these application methods on plant growth, biomass, and certain physiological traits in rapeseed have been demonstrated in several studies (Lally et al., 2017; Farhat et al., 2023; Dobrzyński et al., 2024a, 2024b).

In contrast, direct evidence regarding the agronomic efficacy of PGPR application through irrigation and foliar application in *B. napus* appears to be more limited. Although these application methods may offer potential advantages in delivering PGPR to the target site, their success depends on factors such as bacterial viability, formulation characteristics, environmental conditions, and successful colonization of the target tissue (Bashan et al., 2014; Santoyo et al., 2021). However, the cited studies do not directly evaluate the agronomic efficacy of PGPR application through irrigation or foliar spraying in *B. napus*; rather, they provide general information on PGPR inoculant application technology, bacterial viability, and colonization processes. Therefore, irrigation and foliar applications may be considered potential alternative application methods for *B. napus*; however, their efficacy under different PGPR strains, formulations, application timings, and environmental conditions needs to be investigated in greater detail through controlled and field experiments.

Table 1. Comparative evaluation of PGPR application methods in Brassica napus L. cultivation

Application method	Application timing	Main objective	Major advantage	Major limitation
Seed inoculation/coating	Before sowing or at sowing	To support early root colonization	Easy to apply; can deliver bacteria to the root zone at an early stage	Seed treatments, storage conditions, and bacterial viability may affect efficacy
Root/rhizosphere application	After emergence or during early development	To support colonization of the root zone	Direct contact with roots	Influenced by soil properties and indigenous microbiota
Soil application	Before sowing–early development	To deliver PGPR to the root zone	Direct application to the root environment	Influenced by moisture, pH, temperature, and microbial communities

Application method	Application timing	Main objective	Major advantage	Major limitation
Irrigation application	Post-emergence–vegetative growth	To deliver bacteria to the root zone through irrigation water	Potential compatibility with irrigation systems	Problems related to bacterial viability, distribution, and colonization
Foliar application	Vegetative/reproductive stages	To deliver bacteria to leaf surfaces	Alternative to root-based application	UV radiation, desiccation, and rainfall may affect bacterial viability

Sources: Lally et al. (2017); Farhat et al. (2023); Dobrzyński et al. (2024a, 2024b); Abdel Latef et al. (2021); Bashan et al. (2014); Santoyo et al. (2021).

3.1. Interactions with Mineral Fertilizers

One of the most realistic applications of PGPR in rapeseed production is not the complete elimination of mineral fertilizers but the improvement of nutrient use efficiency. PGPR have been reported to support rapeseed growth under reduced nitrogen application (Naseri et al., 2013). However, this finding should not be interpreted as evidence that PGPR are a general substitute for mineral nitrogen fertilizers. Similarly, the effects of phosphate-solubilizing bacteria depend on factors such as soil pH, the chemical form of phosphorus, moisture, and microbial competition. Therefore, integrating PGPR applications into fertilization programs developed on the basis of soil analysis and crop nutrient requirements represents a more appropriate approach.

4. EFFECTS OF PGPR ON PLANT GROWTH, NUTRITION, AND YIELD IN RAPESEED

Although positive changes in growth, photosynthesis, and nutrient uptake are frequently reported in PGPR studies, the more important agronomic question is to what extent these changes translate into biomass production, seed yield, and product quality. Evaluation of the available literature from this perspective indicates that the magnitude and direction of PGPR effects are not consistent across all traits.

4.1. Root and Shoot Development

One of the most consistently reported effects of PGPR application is improvement in root and shoot development. Changes in root architecture may enhance water and nutrient uptake and consequently contribute to shoot development. Lally et al. (2017) demonstrated that endophytic *Pseudomonas fluorescens* strains and bacterial consortia could affect plant height and biomass of *B. napus* under greenhouse and field conditions. Farhat et al. (2023) likewise reported positive associations between PGPR application and growth-related traits in rapeseed. However, variation in growth responses under different conditions indicates that PGPR should not be regarded as an application that directly and consistently increases plant growth, but rather as a biological interaction influenced by environmental conditions and genotype.

4.2. Photosynthetic Activity

Photosynthetic activity is an important indicator for evaluating the effects of PGPR, particularly under stress conditions. Reductions in photosynthetic pigments and activity under salinity and drought have been reported to be alleviated by certain PGPR applications (Abdel Latef et al., 2021; Rossi et al., 2021). Farhat et al. (2023) also reported that PGPR application in rapeseed could be positively associated with photosynthetic traits and the antioxidant system. However, whether improvements in photosynthetic activity translate directly into higher seed yield has not been demonstrated in every study.

4.3. Nutrient Uptake

Increased nutrient uptake is one of the important indicators of the contribution of PGPR to plant growth. Bacteria possessing phosphorus- and zinc-solubilizing capacities have received particular attention. Jalal-Ud-Din et al. (2024) reported that zinc-solubilizing bacteria could positively affect nutrient acquisition and growth characteristics in rapeseed.

However, the example of boron reported by Masood et al. (2019) demonstrates that increased nutrient uptake does not necessarily lead to a positive growth response. Therefore, the nutritional effects of PGPR should not be evaluated simply in terms of "greater nutrient uptake," but rather in terms of supporting balanced nutrition in accordance with plant requirements.

4.4. Biomass

Biomass is an important indicator reflecting the overall effect of PGPR application on plants. Lally et al. (2017) demonstrated that certain *P. fluorescens* applications could increase *B. napus* biomass. Similarly, Ajijah et al. (2024) reported positive changes in plant height and biomass under both normal and water-stress conditions following application of *Pseudomonas protegens* ML15.

However, an increase in biomass does not necessarily persist at the reproductive stage or translate proportionally into seed yield. Therefore, PGPR studies should evaluate yield components in addition to vegetative growth parameters.

4.5. Yield

Seed yield is one of the most important criteria for determining the agricultural value of PGPR. Available studies indicate that certain PGPR applications can positively affect capsule number, seed number, and total seed yield.

In particular, the field study conducted by Dobrzyński et al. (2024b) is important because it demonstrated that a PGPR consortium could increase root weight and seed yield in winter oilseed rapeseed under field conditions. The consortium treatment was associated with an 18.94% increase in seed yield. Jalal-Ud-Din et al. (2024) likewise reported that zinc-solubilizing PGPR applications could positively affect certain yield-related traits in rapeseed. Nevertheless, the fact that yield responses are not consistent in direction across all studies is an important consideration. Yield is the combined outcome of bacterial strain, genotype, soil nutrient status, water regime, and climatic conditions. Therefore, the yield-promoting effect of PGPR should be considered a condition-dependent agronomic response rather than a fixed biological outcome.

4.6. Seed and Oil Characteristics

In rapeseed production, oil content and oil quality are economically important in addition to seed yield. Jalal-Ud-Din et al. (2024) reported that certain zinc-solubilizing PGPR isolates could positively affect seed oil characteristics. However, studies on the effects of PGPR on oil content and fatty acid composition in *B. napus* remain relatively limited compared with the literature on plant growth and stress tolerance. Therefore, future studies should evaluate not only seed yield but also oil content, fatty acid profiles, and other quality parameters.

5. PGPR UNDER ABIOTIC STRESS CONDITIONS

5.1. Drought

Drought is an important stress factor that can cause yield losses in rapeseed, particularly during critical developmental stages. Water deficiency can result in stomatal closure, reduced photosynthetic activity, and increased oxidative stress. The potential role of PGPR in drought tolerance has been associated with mechanisms such as promotion of root development, ACC deaminase activity, regulation of antioxidant defense, and improvement of plant water relations (Chandwani & Amaresan, 2022; Shahid et al., 2023). Ajijah et al. (2024) demonstrated that application of the EPS-producing *P. protegens* ML15 positively affected several traits in rapeseed under drought conditions, including biomass, chlorophyll, proline, and antioxidant enzyme activity. A notable feature of the study was that the bacterium promoted plant growth under both normal and water-stress conditions. Tanveer et al. (2023) reported that the combined application of *Pseudomonas putida* and salicylic acid could improve the response of rapeseed to drought stress. However, because the bacterium and salicylic acid were applied together, the observed effects cannot be attributed exclusively to PGPR. Similarly, positive effects of biochar–PGPR combinations under drought conditions have been reported (Lalay et al., 2024). These studies indicate the potential of PGPR in drought management but also demonstrate the need for experiments that distinguish the effects of PGPR alone from those of combination treatments.

5.2. Salinity

Salinity limits rapeseed growth through osmotic stress, accumulation of Na^+ and Cl^-, nutrient imbalance, and oxidative stress. Saghafi et al. (2019) reported that halotolerant *Rhizobium* strains possessing ACC deaminase activity could promote growth and salt tolerance in *B. napus* seedlings. Abdel Latef et al. (2021) demonstrated that application of *Azotobacter chroococcum* and *Alcaligenes faecalis* could positively affect growth, photosynthetic pigments, mineral nutrition, and the antioxidant system in rapeseed grown under saline soil conditions. Findings reported by Rossi et al. (2021) likewise indicated that PGPB applications could improve photosynthetic activity and oxidative stress responses in rapeseed grown in saline soil. Swiontek Brzezinska et al. (2022) further reported that PGPR consortia could support rapeseed growth under both normal and saline conditions. Although these findings are generally consistent with one another, a substantial proportion of the studies were conducted under controlled or semi-controlled conditions. Therefore, the efficacy of PGPR under salinity stress needs to be validated under diverse field conditions.

5.3. Heavy Metal Stress

Heavy metal toxicity can adversely affect root development, photosynthesis, mineral nutrition, and oxidative balance. *B. napus* is also used in phytoremediation research because of its high biomass production and capacity to accumulate certain metals. The effects of PGPR under heavy metal stress may be evaluated differently depending on the purpose of cultivation. In phytoremediation, increased metal uptake is desirable, whereas in food and feed production, limiting metal transfer to the plant is generally preferred. Dąbrowska et al. (2017) demonstrated that PGPR applications could affect Cd and Zn phytoextraction in *B. napus*. Zheng et al. (2023) reported that application of Sb-resistant PGPR could promote growth in rapeseed seedlings and alter Sb uptake. Therefore, the effect of PGPR under heavy metal stress is not governed by a single mechanism of either “increasing” or “decreasing” metal uptake. Metal type, bacterial strain, soil properties, and the intended purpose of cultivation determine the direction of the response. Studies conducted on *Brassica juncea* under Cd and Cr stress have also reported positive effects of PGPR application on photosynthetic characteristics and the antioxidant system (Sharma et al., 2023; Bhardwaj et al., 2024). However, these studies should be considered supportive evidence from the genus *Brassica* rather than direct evidence for *B. napus*.

6. DISEASE MANAGEMENT AND PGPR CONSORTIA

The potential of PGPR is not limited to abiotic stress. Certain bacteria can directly suppress pathogens by producing antifungal metabolites and hydrolytic enzymes or induce induced systemic resistance (ISR) in plants (Elnahal et al., 2022; Yu et al., 2022). Danielsson et al. (2007) reported that *Bacillus amyloliquefaciens* strains could provide protection against certain fungal pathogens in oilseed rapeseed. Lipková et al. (2021) highlighted the potential of endophytic bacteria to promote *B. napus* growth and suppress blackleg disease caused by *Leptosphaeria maculans*. In contrast, studies demonstrating the disease-suppressive potential of antagonistic rhizobacteria against *Alternaria brassicae* in *B. juncea* (Sharma et al., 2018) provide mechanistic support across *Brassica* species but should not be considered direct evidence for rapeseed. More recent research indicates that the biocontrol effects of PGPR do not rely solely on direct pathogen suppression, but also involve stimulation of the plant defense system (Mashabela et al., 2022; Yu et al., 2022; Zhu et al., 2022). Nowak et al. (2025) demonstrated the biocontrol and plant growth-promoting potential of *Priestia megaterium* KW16 against *Rhizoctonia solani* in oilseed rapeseed. Nevertheless, more comprehensive field studies are required to determine whether in vitro antagonistic activity can translate into effective disease control under field conditions.

6.1. PGPR Consortia

It is unlikely that a single PGPR strain will simultaneously perform multiple functions, such as nitrogen fixation, phosphate solubilization, IAA production, ACC deaminase activity, and biocontrol, at high levels. Therefore, the use of bacteria with complementary functions in consortium-based applications has become an important research area. Lally et al. (2017) and Swiontek Brzezinska et al. (2022) demonstrated that bacterial consortia could support *B. napus* growth. However, competition or antagonistic interactions may occur among bacteria within consortia, and therefore it should not be assumed that increasing the number of bacterial strains will automatically result in greater efficacy.

The studies conducted by Dobrzyński et al. (2024a, 2024b) are particularly relevant in this regard. One study reported that a PGPB consortium altered the rhizobacterial community in winter oilseed rapeseed and provided limited but measurable support for plant growth. Another study demonstrated that applications of *Pseudomonas* sp. G31 and *Azotobacter* sp. PBC2 altered bacterial community structure and provided modest support for oilseed rapeseed growth. These findings indicate that PGPR consortia can modify not only plant growth directly but also the structure of rhizosphere microbial communities. Therefore, future studies would benefit from evaluating plant responses and microbiome responses simultaneously.

7. EFFICACY AND APPLICATION LIMITATIONS UNDER FIELD CONDITIONS

One of the major challenges in translating PGPR research into practical agricultural applications is the variability of their performance under field conditions. Unlike controlled experiments, field environments involve simultaneous and dynamic interactions among soil characteristics, weather conditions, crop genotype, indigenous microbiota, and agricultural management practices. Consequently, PGPR treatments that produce clear responses under greenhouse or other controlled conditions may show weaker or less consistent effects in the field. Field studies in *B. napus* illustrate this variability. Dobrzyński et al. (2024a, 2024b) demonstrated that PGPB applications could modify the structure of bacterial communities in the rapeseed rhizosphere, while the corresponding effects on plant growth remained limited under some conditions. This finding suggests that successful modification of the rhizosphere microbiome does not necessarily result in a proportionate agronomic response. In contrast, Lally et al. (2017) reported positive effects of certain *Pseudomonas fluorescens* treatments under both greenhouse and field conditions, although the magnitude of the response differed between environments. Such findings indicate that PGPR efficacy should be evaluated not only in terms of whether a treatment produces a positive response, but also in terms of the consistency and magnitude of that response across contrasting environments.

The transition from controlled experiments to field-scale application therefore represents an important step in PGPR research. Field validation should include repeated trials across locations and growing seasons and should consider agronomically relevant parameters such as seed yield, yield components, seed quality, and economic return. Measurements of bacterial persistence and root colonization may also help explain differences between experimental environments. Accordingly, greenhouse experiments remain valuable for identifying promising strains and elucidating mechanisms, but field trials are essential for determining their practical agricultural value.

7.1. Formulation and Application Timing

Beyond environmental variability, the practical effectiveness of PGPR depends on the ability of the inoculant to remain viable and functional throughout production, storage, application, and establishment in the crop. Formulation characteristics, carrier materials, shelf life, storage temperature, and compatibility with seed treatments are therefore important considerations for commercial development (Bashan et al., 2014). An effective strain under laboratory conditions may have limited practical value if its viability declines substantially during storage or application.

Application timing is another important consideration. Early application may facilitate bacterial establishment during initial root development, whereas applications before or during periods of environmental stress may provide an opportunity for beneficial interactions to become established before stress intensity increases. However, no universal optimum bacterial density or application timing has yet been established for *B. napus*. The appropriate strategy is therefore likely to depend on the biological characteristics of the selected strain, the crop developmental stage, the formulation, and the intended agronomic objective.

For practical implementation, PGPR technology should consequently be evaluated as a complete application system rather than solely on the basis of bacterial performance. The interaction among strain, formulation, application method, timing, crop genotype, and environmental conditions should be considered when developing recommendations for field use. Standardization of these factors, together with multi-location field validation, will be essential for improving the reliability and reproducibility of PGPR applications in *B. napus* production.

8. FUTURE RESEARCH

In PGPR studies involving rapeseed, traits capable of promoting plant growth, including phosphorus and zinc solubilization, nitrogen fixation, IAA production, siderophore production, and ACC deaminase activity, have been reported in different bacterial strains. A second important research area is strain–genotype compatibility. Because root exudates and rhizosphere microbiota may differ among rapeseed genotypes, identifying PGPR strains that are better adapted to specific genotypes may improve efficacy. Third, research should move beyond single-stress conditions toward multiple-stress scenarios. Under actual field conditions, drought, high temperature, salinity, and nutrient deficiency may occur simultaneously or sequentially. In addition, inoculum density, application method, formulation, and application timing need to be standardized. Seed coating, soil application, and other application methods should be compared under the same experimental conditions, while bacterial root colonization and persistence throughout the field should be directly monitored.

The use of microbiome, transcriptomic, and metabolomic approaches may contribute to understanding why PGPR are successful in certain genotypes and environments but have limited effects in others. However, these approaches should be regarded as tools for explaining fundamental agronomic outcomes, including plant growth, yield, and product quality. Finally, the economic feasibility of PGPR technology should also be investigated. Bacterial production costs, shelf life, ease of application, efficacy under field conditions, and the actual reduction in mineral fertilizers or other chemical inputs that can be achieved will determine the commercial success of the technology.

9. CONCLUSION

The available evidence indicates that certain PGPR strains and consortia can positively affect root and shoot development, nutrient uptake, photosynthetic activity, biomass production, some yield components, and particularly plant responses to abiotic stresses such as drought and salinity in *Brassica napus* L. production. However, these effects do not occur with the same magnitude under all conditions, and bacterial strain, plant genotype, soil properties, environmental conditions, rhizosphere microbiota, and application method can substantially modify the outcomes.

An integrated evaluation of the literature suggests that the most prominent potential of PGPR lies not merely in increasing plant biomass, but in supporting plant adaptation to environmental conditions through improved nutrient use efficiency, stress responses, and root–rhizosphere interactions. Nevertheless, it should be recognized that positive changes in vegetative growth do not always translate into equivalent increases in seed yield or oil quality. Therefore, future studies should evaluate seed yield, oil content, oil quality, and economic returns together rather than focusing primarily on growth parameters.

Field studies, in particular, indicate that the effects of PGPR applications may be less pronounced and less consistent under field conditions than under controlled environments. Accordingly, rather than considering PGPR as direct substitutes for mineral fertilizers, irrigation, or chemical disease management, it appears more realistic to regard them as complementary biological inputs that support existing crop management practices.

In conclusion, realizing the full agricultural potential of PGPR in *B. napus* production will depend on multi-location field trials, identification of strain–genotype compatibility, verification of bacterial colonization, standardization of formulations and application methods, and evaluation based on yield, quality, and economic performance. Such an approach may enable PGPR technology to progress from promising results at the laboratory and greenhouse levels toward a reproducible and practically applicable agricultural technology.

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RELATIONSHIPS AMONG LEAF MINERAL ELEMENTS IN SEAWEED-TREATED PEANUT UNDER SALINITY STRESS: A CORRELATION ANALYSIS

TUZLULUK STRESI ALTINDA DENİZ YOSUNU UYGULANAN YERFISTIĞINDA YAPRAK MİNERAL ELEMENTLERI ARASINDAKI İLİŞKİLER: BİR KORELASYON ANALİZİ

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ABSTRACT

Salinity is one of the major abiotic stresses limiting crop growth, productivity, and nutritional balance. High NaCl concentrations can promote Na^+ accumulation and disrupt the homeostasis of essential mineral nutrients in plants. Seaweed-derived biostimulants have attracted attention because of their potential to support plant growth, nutrient acquisition, and stress responses. In the present study, relationships among leaf mineral elements were evaluated using Pearson correlation analysis in four peanut cultivars (‘Ayşe Hanım’, ‘Halis Bey’, ‘NC-7’, and ‘Albenek’) grown under different salinity levels and seaweed application treatments. Leaf concentrations of Na, Ca, K, Mg, P, Zn, Mn, Cu, and Fe were determined. All pairwise correlations among the mineral elements were statistically significant ($p < 0.01$). Na showed negative correlations with all other mineral elements, with the strongest associations observed with Fe (r = −0.93), K (r = −0.90), P (r = −0.84), Cu (r = −0.82), and Mg (r = −0.80). In contrast, Ca, K, Mg, P, Zn, Mn, Cu, and Fe generally showed positive correlations with one another. The strongest positive associations were observed for K–Fe (r = 0.87), Mg–Fe (r = 0.84), Cu–Fe (r = 0.83), P–Cu (r = 0.83), and K–P (r = 0.82). These findings demonstrate that leaf Na concentration was strongly associated with the concentrations of several essential mineral nutrients, particularly Fe and K, across the experimental dataset. The strong negative association between Na and K highlights the relevance of Na^+/K^+ relationships when evaluating mineral nutritional responses of peanut under saline conditions. However, the observed correlations represent statistical associations and should not be interpreted as evidence of direct causal relationships or specific effects of seaweed application. Further studies using treatment-specific analyses and physiological measurements are needed to clarify the mechanisms underlying these mineral associations and to assess the potential contribution of seaweed-derived biostimulants to nutrient homeostasis under salinity stress.

Keywords: *Arachis hypogaea* L., salinity, seaweed extract, biostimulant, mineral nutrition, Na^+, K^+, mineral elements, Pearson correlation

ÖZET

Tuzluluk, bitkilerde büyümeyi, verimliliği ve mineral besin dengesini sınırlandıran başlıca abiyotik stres faktörlerinden biridir. Yüksek NaCl konsantrasyonları, bitkilerde Na^+ birikimini artırabilmekte ve temel mineral besin elementlerinin homeostazını bozabilmektedir. Deniz yosunu kökenli biyostimülantlar ise bitki büyümesini, besin maddelerinin alımını ve stres yanıtlarını destekleme potansiyelleri nedeniyle dikkat çekmektedir. Bu çalışmada, farklı tuzluluk düzeyleri ve deniz yosunu uygulamaları altında yetiştirilen dört yerfıstığı çeşidinde (‘Ayşe Hanım’, ‘Halis Bey’, ‘NC-7’ ve ‘Albenek’) yaprak mineral elementleri arasındaki ilişkiler Pearson korelasyon analizi kullanılarak değerlendirilmiştir. Yapraklardaki Na, Ca, K, Mg, P, Zn, Mn, Cu ve Fe konsantrasyonları belirlenmiştir. Mineral elementler arasındaki tüm ikili korelasyonlar istatistiksel olarak önemli bulunmuştur ($p < 0,01$). Na, incelenen diğer tüm mineral elementlerle negatif korelasyon göstermiş; en güçlü ilişkiler Fe (r = −0,93), K (r = −0,90), P (r = −0,84), Cu (r = −0,82) ve Mg (r = −0,80) ile belirlenmiştir. Buna karşılık, Ca, K, Mg, P, Zn, Mn, Cu ve Fe genel olarak birbirleriyle pozitif korelasyon göstermiştir. En güçlü pozitif ilişkiler K–Fe (r = 0,87), Mg–Fe (r = 0,84), Cu–Fe (r = 0,83), P–Cu (r = 0,83) ve K–P (r = 0,82) arasında belirlenmiştir. Bu bulgular, deneysel veri seti genelinde yaprak Na konsantrasyonunun, özellikle Fe ve K olmak üzere, çeşitli temel mineral besin elementlerinin konsantrasyonlarıyla güçlü biçimde ilişkili olduğunu göstermektedir.

Na ile K arasındaki güçlü negatif ilişki, tuzlu koşullarda yerfıstığının mineral beslenmeye verdiği yanıtların değerlendirilmesinde Na^+/K^+ ilişkilerinin dikkate alınmasının önemini ortaya koymaktadır. Bununla birlikte, gözlenen korelasyonlar istatistiksel ilişkileri ifade etmekte olup doğrudan nedensel ilişkilerin veya deniz yosunu uygulamasına özgü etkilerin kanıtı olarak yorumlanmamalıdır. Bu mineral ilişkilerinin altında yatan mekanizmaların açıklığa kavuşturulması ve deniz yosunu kökenli biyostimülantların tuzluluk stresi altında besin elementi homeostazına olası katkısının değerlendirilmesi için uygulama bazlı analizler ve fizyolojik ölçümler içeren ileri çalışmalara ihtiyaç vardır.
Anahtar Kelimeler: *Arachis hypogaea* L., tuzluluk, deniz yosunu ekstraktı, biyostimülant, mineral beslenme, Na^+, K^+, mineral elementler, Pearson korelasyonu

1. INTRODUCTION

Peanut (*Arachis hypogaea* L.) is an important legume and oilseed crop because of its nutritional value and contribution to edible oil and protein production. However, increasing soil salinity is an important constraint to sustainable peanut production (Shahid et al., 2020; Singh, 2022). Salinity imposes both osmotic and ionic stress, disrupts water and nutrient relations, and can ultimately reduce plant growth and productivity (Shahid et al., 2020; Singh, 2022). Previous studies have also demonstrated that increasing salinity can adversely affect growth, yield, and physiological characteristics of peanut (Chen et al., 2019; Cruz et al., 2021; Meena et al., 2024).

Plant responses to salinity are closely associated with the maintenance of ionic homeostasis, particularly the balance between Na^+ and K^+ (Adams and Shin, 2014; Shabala and Cuin, 2008). Excessive Na^+ accumulation may interfere with K^+ uptake, transport, and cellular homeostasis, thereby altering the K^+/Na^+ balance under saline conditions (Adams and Shin, 2014; Shabala and Cuin, 2008). Potassium is an essential macronutrient involved in osmotic regulation, stomatal function, enzyme activation, and several other physiological processes. Therefore, maintaining K^+ homeostasis is considered an important component of plant adaptation to salinity and other abiotic stresses (Adams and Shin, 2014; Khalil et al., 2022).

Salinity can also affect the uptake, transport, and distribution of other essential mineral nutrients, including Ca, Mg, P, Fe, Zn, Mn, and Cu, thereby influencing overall plant nutritional status (Shahid et al., 2020). Consequently, evaluating individual nutrient concentrations alone may not fully characterize the nutritional response of plants to salt stress. Examining relationships among mineral elements may provide additional information about coordinated changes in nutrient concentrations under different environmental and management conditions. In particular, interactions among mineral nutrients may be influenced by plant nutritional status and environmental conditions (Xie et al., 2021).

Correlation analysis provides a statistical approach for assessing the direction and strength of associations among plant characteristics (Kayaçetin, 2022a,b). Such analyses can complement comparisons of treatment means by identifying coordinated patterns of variation among physiological or nutritional variables. However, correlations obtained from pooled experimental observations should be interpreted as statistical associations rather than evidence of direct physiological interactions or causal relationships.

Seaweed extracts have emerged as promising plant biostimulants because they contain minerals, polysaccharides, amino acids, and other biologically active compounds that may influence plant growth, nutrient acquisition, and stress responses (Ali et al., 2021). Their potential under saline conditions has also received increasing attention, particularly with respect to maintaining plant physiological performance and nutrient balance (Lakhdar et al., 2023).

The potential of seaweed-based products has also been investigated in peanut. Meng et al. (2022) reported beneficial effects of seaweed fertilizer application on peanut growth and physiological performance. Furthermore, Pal et al. (2024) reported that seaweed extract application reduced leaf Na^+ accumulation and increased leaf K^+ and P concentrations in bell pepper under saline conditions, suggesting that seaweed-derived biostimulants may influence mineral nutrient balance under salt stress. Zhang et al. (2024) also reported significant differences in mineral accumulation and relationships among mineral elements in peanut grown under saline and non-saline conditions.In a previous study conducted using the same experimental material, increasing NaCl concentrations affected growth, physiological traits, and leaf mineral concentrations, whereas seaweed application modified several of these responses, particularly under non-saline and mild saline conditions (Kocak Sahin, 2025).

These findings provide a basis for further examining the relationships among mineral elements within the same experimental system.

Although previous studies have provided valuable information on mineral accumulation and nutritional responses of peanut to salinity, the relationships among leaf mineral elements in seaweed-treated peanut grown under controlled salinity conditions remain insufficiently characterized. Therefore, the objective of the present study was to determine the direction and strength of relationships among Na, Ca, K, Mg, P, Zn, Mn, Cu, and Fe concentrations in peanut leaves using Pearson correlation analysis.

The hypothesis was that leaf Na concentration would be negatively associated with essential mineral nutrients, particularly K, whereas the other mineral nutrients would generally show positive associations with one another.

2. MATERIALS AND METHODS

2.1. Plant material and experimental conditions

Four peanut cultivars, namely 'Ayşe Hanım', 'Halis Bey', 'NC-7', and 'Albenek', were used in the experiment. The study was conducted under controlled greenhouse conditions at the Department of Field Crops, Faculty of Agriculture, Ankara University, Türkiye. The experiment was established with four replications.

Salinity treatments consisted of 0, 50, 100, 150, and 200 mM NaCl. Seaweed application consisted of two treatments: an untreated control and seaweed extract application at 5 g L^{-1}. The commercial seaweed preparation contained 45% organic matter, 2% alginic acid, and 15% water-soluble K_2O.

2.2. Mineral element analysis

Leaf samples were analyzed for Na, Ca, K, Mg, P, Fe, Mn, Zn, and Cu concentrations. Mineral element analyses were performed following wet digestion with nitric and perchloric acids using inductively coupled plasma optical emission spectrometry (ICP-OES).

2.3. Statistical analysis

Pearson correlation coefficients (r) were calculated to assess the direction and strength of associations among Na, Ca, K, Mg, P, Zn, Mn, Cu, and Fe concentrations in peanut leaves. The correlation analysis was based on 160 observations, representing four cultivars, five salinity levels, two seaweed treatments, and four replications. Statistical significance was assessed at $p < 0.01$.

3. RESULTS AND DISCUSSION

Pearson correlation analysis revealed significant associations among all mineral elements evaluated in peanut leaves ($p < 0.01$; Table 1; Figure 1). A clear correlation pattern was observed, characterized by negative associations between Na and all other mineral elements, whereas Ca, K, Mg, P, Zn, Mn, Cu, and Fe were positively correlated with one another. These results indicate that mineral concentrations varied in a coordinated manner across the pooled experimental observations.

The strongest negative association was observed between Na and Fe ($r = -0.93$), followed by Na–K ($r = -0.90$), Na–P ($r = -0.84$), Na–Cu ($r = -0.82$), and Na–Mg ($r = -0.80$). The strong negative association between Na and K is particularly relevant because the maintenance of K^+/Na^+ homeostasis is considered an important component of plant responses to salinity (Adams and Shin, 2014; Shabala and Cuin, 2008). Potassium plays important roles in osmotic regulation, stomatal function, and enzyme activity, and adequate K^+ homeostasis contributes to plant adaptation to saline conditions (Khalil et al., 2022). Thus, the strong Na–K association observed in the present study indicates that variation in leaf Na concentration was closely accompanied by variation in leaf K concentration across the experimental dataset.

This finding is also relevant in the context of studies investigating seaweed-derived biostimulants under saline conditions. Pal et al. (2024) reported reduced leaf Na^+ accumulation and increased leaf K^+ and P concentrations following seaweed extract application in bell pepper under salinity. Although the present study evaluated correlations rather than treatment effects, both studies emphasize the importance of Na^+ and K^+ balance in plant responses to salinity. Nevertheless, the negative correlation observed here should not be interpreted as evidence that Na directly inhibited K^+ uptake or that seaweed application was responsible for the observed association.

Na also showed strong negative associations with P (r = −0.84), Cu (r = −0.82), and Mg (r = −0.80). Negative associations were also observed for Ca (r = −0.73), Zn (r = −0.69), and Mn (r = −0.58). Thus, higher leaf Na concentrations tended to coincide with lower concentrations of several essential mineral nutrients. The relatively weaker Na–Mn association compared with the other relationships suggests that the strength of the association differed among mineral elements. Zhang et al. (2024) also reported significant correlations among mineral elements in peanut grown under saline and non-saline conditions. In their study, Na was negatively correlated with Mn and Ca but positively correlated with Zn. In contrast, Na was negatively correlated with all other mineral elements in the present study, with particularly strong associations with Fe, K, P, Cu, and Mg. These differences may reflect differences in plant tissue, growing conditions, and experimental design between the two studies.

The positive correlations among Ca, K, Mg, P, Zn, Mn, Cu, and Fe represented the second major pattern in the correlation matrix. The strongest positive associations were observed for K–Fe (r = 0.87), Mg–Fe (r = 0.84), Cu–Fe (r = 0.83), P–Cu (r = 0.83), and K–P (r = 0.82). Other relatively strong associations included K–Cu (r = 0.80), Mg–P (r = 0.79), K–Mg (r = 0.78), Mg–Cu (r = 0.78), and Zn–Fe (r = 0.78). These relationships indicate that several mineral nutrients exhibited similar patterns of variation across the experimental observations.

The positive association between K and Mg (r = 0.78) is noteworthy because these nutrients may interact within plant nutritional processes. Depending on nutritional status and environmental conditions, K and Mg can exhibit either synergistic or antagonistic relationships (Xie et al., 2021). Therefore, the positive correlation observed in the present study suggests coordinated variation in their leaf concentrations but does not demonstrate a direct physiological interaction between K and Mg.

Similarly, the strong positive associations involving Fe, particularly K–Fe (r = 0.87) and Mg–Fe (r = 0.84), indicate coordinated variation among these nutrients. Iron is involved in electron transport and photosynthetic metabolism, whereas K and Mg contribute to enzyme activity, osmotic regulation, and photosynthetic processes. However, the correlation coefficients alone cannot determine whether these nutrients directly influenced one another. The observed associations may instead reflect common responses to salinity, cultivar differences, seaweed treatment, or combinations of these factors.

The strong P–Cu association (r = 0.83) likewise indicates coordinated variation between these elements. However, because the present analysis was based on pooled observations, the correlation cannot be used to infer a direct physiological relationship between P and Cu.Previous studies have demonstrated that salinity can substantially affect peanut growth, productivity, and physiological characteristics. Cruz et al. (2021) reported negative effects of increasing salinity in irrigation water on several yield-related characteristics of peanut, whereas Meena et al. (2024) observed reductions in peanut productivity and biochemical characteristics under prolonged salinity stress. These studies provide broader support for the influence of salinity on multiple aspects of peanut performance but do not provide direct evidence for the mineral correlations observed in the present study.

Table 1. Pearson correlation coefficients among leaf mineral elements in seaweed-treated peanut under salinity stress

Element	Na	Ca	K	Mg	P	Zn	Mn	Cu	Fe
Na	1.00	−0.73**	−0.90**	−0.80**	−0.84**	−0.69**	−0.58**	−0.82**	−0.93**
Ca		1.00	0.73**	0.62**	0.74**	0.65**	0.68**	0.75**	0.68**
K			1.00	0.78**	0.82**	0.74**	0.64**	0.80**	0.87**
Mg				1.00	0.79**	0.73**	0.60**	0.78**	0.84**
P					1.00	0.75**	0.67**	0.83**	0.81**
Zn						1.00	0.64**	0.74**	0.78**
Mn							1.00	0.72**	0.58**
Cu								1.00	0.83**
Fe									1.00

Note: Values represent Pearson correlation coefficients (*r*). Significant at $p < 0.01$.

The present findings can also be considered in relation to the previous experiment conducted using the same four peanut cultivars and seaweed-based biostimulant. Kocak Sahin (2025) reported that increasing NaCl concentrations affected several growth, physiological, and leaf mineral characteristics, while seaweed application modified some of these responses. The present correlation analysis complements those findings by demonstrating significant associations among mineral elements across the experimental observations.

Importantly, the correlation matrix does not separate the effects of salinity, seaweed application, and cultivar. For example, two mineral elements may show a high correlation because they respond similarly to increasing salinity, differ among cultivars, respond to seaweed application, or are simultaneously influenced by more than one experimental factor. Therefore, the present results should be interpreted as overall statistical associations rather than evidence of direct effects of seaweed application or causal relationships among mineral elements.

From a nutritional perspective, the strong negative association between Na and K is one of the most prominent findings of the present analysis. It highlights the importance of considering Na^+/K^+ relationships when evaluating mineral nutritional responses of peanut under saline conditions, given the recognized role of K^+/Na^+ homeostasis in salinity tolerance (Adams and Shin, 2014; Shabala and Cuin, 2008). The associations involving P, Mg, Cu, and Fe further suggest that mineral nutrition under salinity should be considered as an integrated system rather than through individual nutrient concentrations alone.

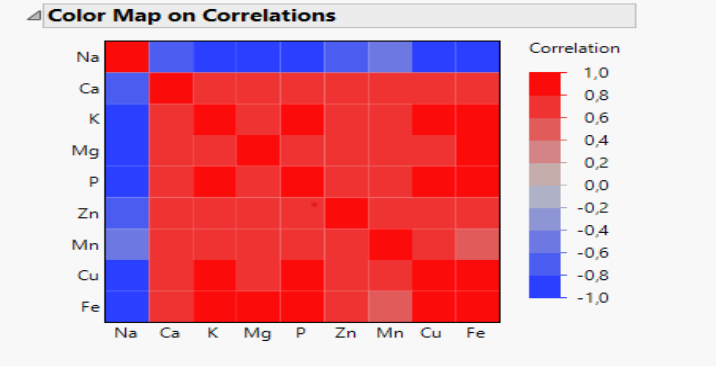


Figure 1. Heatmap of Pearson correlation coefficients among leaf mineral elements in seaweed-treated peanut under salinity stress

The correlation matrix revealed two major patterns: a strong negative association of Na with the other mineral elements and predominantly positive associations among Ca, K, Mg, P, Zn, Mn, Cu, and Fe. Although these patterns demonstrate substantial coordination among mineral concentrations, they do not establish causal relationships. Treatment-specific correlation analyses, nutrient ratios such as K^+/Na^+, regression approaches, and physiological measurements would be valuable for further clarifying the mechanisms underlying these associations.

4. CONCLUSION

The correlation analysis revealed significant relationships among leaf Na, Ca, K, Mg, P, Zn, Mn, Cu, and Fe concentrations in seaweed-treated peanut under salinity stress. Na showed negative correlations with all other mineral elements, with the strongest associations observed for Fe, K, P, Cu, and Mg. In contrast, Ca, K, Mg, P, Zn, Mn, Cu, and Fe were generally positively correlated with one another, indicating coordinated variation in leaf mineral concentrations across the experimental observations.

The strong negative association between Na and K highlights the importance of considering Na^+/K^+ relationships when evaluating the mineral nutritional responses of peanut under saline conditions. The associations among P, Mg, Cu, Fe, and other mineral elements further indicate that mineral nutrition under salinity involves coordinated changes among multiple nutrients.

However, because the correlation analysis was based on pooled observations across cultivars, salinity levels, and seaweed treatments, the observed relationships should be interpreted as statistical associations rather than causal relationships.

The correlation matrix cannot determine whether salinity, seaweed application, cultivar, or interactions among these factors were primarily responsible for the observed patterns.

The present findings, together with previous evidence from peanut under saline conditions, highlight the importance of considering mineral nutrient relationships, particularly the Na^+/K^+ balance, when evaluating peanut responses to salinity.

Further studies incorporating treatment-specific correlation analyses, K^+/Na^+ ratios, regression models, and physiological or molecular measurements are needed to clarify the mechanisms underlying these mineral relationships and to determine the potential role of seaweed-derived biostimulants in maintaining mineral nutrient homeostasis in peanut under salinity stress.

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RELATIONAL KNOWLEDGE VERSUS THE STANDPOINT OF MASTERY: KIM STANLEY ROBINSON'S FORTY SIGNS OF RAIN AND MICHAEL CRICHTON'S STATE OF FEAR

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ÖZET
Bu çalışma, Kim Stanley Robinson'ın *Forty Signs of Rain* (2004) ve Michael Crichton'ın *State of Fear* (2004) adlı eserlerinin karşılaştırmalı bir okumasını sunar. Val Plumwood'un kullandığı ikilikçi "mastery" (hâkimiyet/tahakküm) kavramından yola çıkan çalışma, söz konusu iki romanın iklim bilimi ve politikası konusunda zıt epistemolojik yaklaşımlar sergilediğini savunur. Çalışma, Robinson'ın anlatısının bilim, politika ve özenin (care) iç içe geçtiği ilişkisel ve işbirlikçi bir bilgi modelini uyguladığını gösterir. Öte yandan Crichton'ın anlatısı, iklim krizine verilen tepkinin ilişkisel ve duygusal boyutlarını dışlayan eril bir ustalık/hâkimiyet söylemini yeniden üretir. Ana karakterlerin, retorik stratejilerin ve farklı bakış açılarının yakından incelenmesi, bu karşıtlığın her iki romanda da kimin bilgi sahibi olmasına izin verildiğini ve bu bilginin hangi koşullar altında kabul edildiğini ortaya koyar. Çalışma, Robinson'ın bilgi anlayışının iklim değişikliğini azaltma ve iklim değişikliğine uyum sağlama konusundaki gerçek dünya uygulamalarıyla nasıl ilişkili olduğunu inceleyerek bu analizi genişletir. Romanlarda ortaya konan farklı bilgi anlayışlarının, sadece hikâyelerle sınırlı kalmayıp daha geniş bir anlam taşıdığını savunur. Her iki eser de iklim sorunlarını yorumlama yetkisinin kimde olduğuna dair farklı görüşleri içeren bir tür olan iklim kurgusu (climate fiction) kategorisine girer. Çalışma, biçimsel ve retorik seçimlerin bir iklim romanının politik fikirlerini güçlü bir şekilde şekillendirdiğini savunur. Ayrıca, bu seçimleri anlamak için ekofeminist teorinin yararlı bir yaklaşım olduğunu da öne sürer.
Anahtar Kelimeler: Ekofeminizm, ilişkisel bilgi, hakimiyet, Val Plumwood, Kim Stanley Robinson, Michael Crichton

ABSTRACT
This study offers a comparative reading of Kim Stanley Robinson's *Forty Signs of Rain* (2004) and Michael Crichton's *State of Fear* (2004). Drawing on dualistic concept of "mastery," as used by Val Plumwood, the study argues that the two novels in question exhibit contrasting epistemological stances regarding climate science and politics. It shows that Robinson's narrative implements a relational and collaborative model of knowledge in which science, politics, and care are entangled. Crichton's narrative, on the other hand, reproduces a hyper-masculine discourse of *mastery* that excludes the relational and emotional dimensions of the response to the climate crisis. A close reading of the main characters, rhetorical strategies, and differing perspectives reveals how this opposition shapes who is allowed to have knowledge in each novel, and under what conditions that knowledge is accepted. The study expands on this analysis by examining how Robinson's understanding of knowledge relates to real-world applications of climate mitigation and adaptation. It argues that the different understandings of knowledge depicted in the novels have significance beyond the stories themselves. Both works belong to the category of climate fiction, a genre that involves different views about who has the authority to interpret climate issues. The study argues that formal and rhetorical choices strongly shape the political ideas of a climate novel. It also suggests ecofeminist theory as a useful way to understand these choices.
Keywords: Ecofeminism, relational knowledge, mastery, Val Plumwood, Kim Stanley Robinson, Michael Crichton

INTRODUCTION
Climate fiction, or "cli-fi," emerged in the mid-twentieth century as a genre of literature dealing with environmental disasters. It also engages with the epistemological and political struggles surrounding climate change. These struggles involve questions of who is authorized to speak about climate change, on what grounds, and in whose interest.

This study argues that Kim Stanley Robinson's *Forty Signs of Rain* and Michael Crichton's *State of Fear*, both published in the same year, 2004, address the same subject. The two novels offer two contrasting answers to this question. The difference between them can best be understood through the theoretical framework of climate fiction.

Val Plumwood's *Feminism and the Mastery of Nature* (1993) supplies the essential conceptual tool for this reading. Plumwood argues that Western thought is structured by interlocking dualisms, such as "reason/nature, culture/nature, mind/body, and male/female, master/slave" (1993, p. 43). In these dualities, the first term claims authority over the second and defines itself in contrast to it. The resulting approach is the standpoint of *mastery*. According to Plumwood, "This hyperseparated conception of the human expresses the master perspective, and his desire to exclude women, slaves and animals and keep his distance from them" (p. 72). She insists the domination of nature and the domination of women, slaves, and animals are structurally linked and produced by the same dual logic.

This framework does more than simply relabel the "climate change" content already present in both novels. It offers a way of reading the novels' form, including their rhetorical strategies, the organization of authority and doubt. It also reveals how their approaches to emotion and relationality are shaped by different understandings of gender, power, and ideology. Read in this way, *Forty Signs of Rain* can be interpreted as a work that models a relational epistemology resisting a hegemonic perspective. In the book, Charlie and Anna Quibler approach climate policy through collaboration, internal relations, and care, rather than through unilateral technical authority. In contrast, *State of Fear*, presents what Jeanne Hamming calls a "hypermasculine national style" (2013, p. 26). This situation promotes a data- and control-based positivist discourse.

The analysis proceeds in three stages. The first stage situates both novels within climate fiction genre conventions and Plumwood's framework. The second stage offers close readings of the two novels' competing epistemological approach. The third stage synthesizes academic studies on gender/climate vulnerability, including Alber, Habtezion, and Patterson. This research is treated as material that extends the novels' own understandings of knowledge and power, rather than as separate sociological evidence.

METHODOLOGY

This article employs close reading as its main methodological approach. The analysis compares two novels that share a common subject and publication period but present climate science in very different ways. Rather than summarizing the plot, the analysis focuses on specific narrative choices. These include how each novel distributes authority among its characters, how it presents scientific certainty or skepticism, and how it contrasts collaboration with individual expertise. These narrative choices are examined through the standpoint of "mastery," a concept used by Val Plumwood. This concept helps identify how each text presents knowledge. In some cases, knowledge is treated as something that can be controlled from a distance. In others, it is presented as something developed through relationships and shared experience. This methodology also follows the approach outlined by Greta Garard and Patrick D. Murphy in *Ecofeminist Literary Criticism*. Their approach emphasizes that the form and rhetoric of a text, along with its explicit statements, can provide significant evidence for interpretation. After establishing this framework, the article examines secondary academic works on climate and gender policy**.** This study is not designed as separate supporting evidence. Instead, it helps to examine whether relational and mastery-based patterns identified in novels are also seen in real-world climate practices. In this way, the literary analysis and the external research work together to support the same argument.

THEORETICAL FRAMEWORK

As a critical framework, ecofeminism starts from the premise that the domination of nature and the domination of women share a common ideological origin. Greta Gaard, in *Ecofeminism: Women, Animals, Nature* (1993) frames this as a rejection of the nature/culture dualism underlying patriarchal thought. This dualism locates women, along with animals and the nonhuman world, at the bottom of hierarchy organized around reason and mastery. Val Plumwood's *Feminism and the Mastery of Nature* (1993) develops this premise into a more systematic philosophical account.

For Plumwood, Western reason constitutes itself through a series of paired oppositions "which make it appropriate to call it a dualism rather than just a distinction or a dichotomy" (p. 47). This way of thinking gives authority to those who distance themselves from and control nature, the body, emotions, and femininity.

This study uses the concept of *mastery* as a tool for analyzing the novels' form and arguments, with a focus beyond their explicit statements about gender. Following the method outlined by Greta Gaard and Patrick D. Murphy in *Ecofeminist Literary Criticism: Theory, Interpretation, Pedagogy* (1998), ecofeminist reading examines a text's formal and rhetorical choices. These include its distribution of narrative authority, treatment of doubt and certainty, and handling of affect. Such choices encode a text's relation to the dualisms described by Plumwood. A novel does not have to discuss gender directly to present a masculinist *mastery*. It also does not have to focus on women characters to present a relational and non-dualistic way of knowing. For this method, the key issue is how the novel approaches knowledge of the climate crisis. The question is whether the text reproduces separation and control. It may instead present knowledge as interdependent, collaborative, and embodied.

Climate fiction is particularly useful for this type of analysis. It often presents competing claims about who is the authority on a controversial scientific and political issue. Robert K. J. Killheffer's description of *Forty Signs of Rain* as an "urgent call for us to pull our heads from the sand and confront the threat of climate change" (2004, p. 41) already demonstrates the novel's emphasis on collective responsibility over individual skill. As Christopher Maughan points out, Crichton's *State of Fear*, on the contrary, is based on "discrediting and problematizing the ground on which existing interventions exist or might exist" (2013, p. 53). This study will argue that this is a rhetorical project inseparable from the novel's gender-based distribution of credibility. These two novels serve as a useful example for this analysis. Both novels focus on the politics of climate knowledge. This allows ecofeminists to make the question of who is allowed to have information and how that information is produced an integral part of their plots. Therefore, the question is already present within the novels themselves, it is not being imposed from the outside.

RELATIONAL KNOWLEDGE IN *FORTY SIGNS OF RAIN*

Forty Signs of Rain organizes its climate politics around a structure of collaboration and this structure is itself the novel's most significant ecofeminist gesture. Charlie Quibler is an environmental policy advisor to Senator Phil Chase. He does not develop his approach to climate policy through individual technical authority. Instead, his understanding develops through relationships with others. His marriage to the scientist Anna plays an important role in shaping his understanding. He is also influenced by his connection with the Buddhist monks of Khembalung. The monks come to Washington to advocate for their island nation, which is threatened by rising sea levels. Charlie's understanding of climate policy is also shaped by caring for his infant son. His domestic responsibilities exist along with his policy work. The novel does not separate his family life and his professional work. The novel does not separate Charlie's public and rational role from his private role as a caregiver. His public role is associated with a traditionally "masculine" identity. His private role is connected to his body, emotions, and caregiving responsibilities. By bringing these roles together, the novel presents knowledge as relational. This reflects the kind of relational epistemology that Plumwood contrasts with the standpoint of *mastery*.

This is also significant in terms of the novel's approach to scientific authority. A mastery-focused narrative would place climate truth in one expert voice. That voice would speak with detached certainty. Robinson takes a different approach. He spreads authority across several relationships. Anna provides scientific expertise. The Khembalung monks provide experiential, place-based knowledge of their sinking homeland. Charlie connects these different forms of knowledge through his political work. The novel's character, Roy, directly expresses the political urgency of this collective knowledge: "The Congress, being deeply concerned that the lack of speed in America's conversion from a hydrocarbon to a carbohydrate fuel economy is rapidly leading to chaotic climate changes with a profoundly negative impact on the U.S economy" (Robinson, 2004, p. 25). However, the novel is equally important in defining the limits of official, rational actor politics. Robinson's insistence that "it's easier to destroy the world than to change capitalism even one little bit" (p. 73) expresses the disappointment felt at the failure of the standpoint of *mastery* to produce action because having control over data and arguments does not mean having control over political decisions in the novel.

In this context, Anna Quibler's role deserves special attention. As a scientist working on environmental policy in the US Senate, she holds a position of authority. This position could be presented as a feminine nature controlled by masculine political reason. Instead, Robinson makes her scientific judgment the standard for evaluating political action. Anna's approach, focused on justice and participation, is more important than her technical expertise alone. It offers an alternative to Plumwood's hyperseparated authority. Her expertise is connected to relationships and their consequences; it doesn't stand apart from them.

Read in this way, the novel's urgency, which Killheffer describes above as a "call for us to pull our heads from the sand," goes beyond simply accepting climate science. It calls for a relational approach to climate knowledge. Scientific facts, political action, and care for others are closely linked. Care extends to a spouse, a baby, and a drowning nation. These concerns are treated as equally important, rather than being ranked.

THE RHETORIC OF MASTERY IN STATE OF FEAR

While *Forty Signs of Rain* distributes authority through relationships, *State of Fear* focuses on a single, powerful way of knowing. It presents climate activism and its emotional and collective forms of knowledge as irrational, feminine, and dangerous. As mentioned above, Jeanne Hamming calls the novel's style a "hypermasculine national style". In the novel, this standpoint of *mastery* appears in its most direct literary form.

Crichton reinforces this standpoint through both the novel's structure and its narrative. His scientist characters insist that "the intermixing of science and politics is a bad combination" (Crichton, 2004, p. 581). The claim appears neutral and scientific. However, Plumwood's framework shows that it demands a clear distinction. It separates science from political, relational, and emotional concerns. Robinson's novel treats these concerns as part of scientific knowledge itself. The graph of global temperature and carbon dioxide levels presented in Crichton's novel (Crichton, 2004, p. 86), and the scientist character's pointed question about the 1940–1970 cooling period (p. 87), establish data as the sole legitimate source of authority. This is a rhetorical maneuver Christopher Maughan has described as an attempt to discredit public concerns 'if and when [it is] offered by individuals with no "legal" or "scientific training"' (2013, p. 53). This prevents the participatory and relational model of knowledge that *Forty Signs of Rain* presents as its ethical center.

This is also where the novel's treatment of women becomes especially important. *State of Fear* does not just discredit women as characters; it also discredits a way of knowing that is collective, emotional, activist, and relational. Ecofeminist theory links this mode of knowledge to the feminine side of Plumwood's dualisms. Hamming's argument that the novel "recasts climate change [...] as an ideological conspiracy" that threatens "the sanctified rights of American consumers" (2013, p. 26) can thus be extended. Crichton's novel is closely concerned with the issue of controlling how knowledge is produced. The main threat is the idea that knowledge can be relational, collective, and emotional. Instead, the novel favors knowledge controlled by a rational and individual (implicitly masculine) expert,

BEYOND THE NOVELS: RELATIONAL KNOWLEDGE AS CLIMATE PRACTICE

Forty Signs of Rain presents a relational way of knowing. *State of Fear,* on the other hand, presents a model based on *mastery*. Research on gender and climate vulnerability supports this argument. It shows that Robinson's relational approach also exists in real climate practice. *Mastery*-based policies have often been slow to recognize this approach. Gotelind Alber points out that climate vulnerability depends on "income, assets, education and knowledge" distributed unevenly by gender (2011, p. 7). From a political approach, this describes the same asymmetry that Robinson reveals in his novel. Both novels show that the standpoint of *mastery* overlooks who gets to participate in climate decisions and who simply receives them.

Sandra Bäthge argues that women are more vulnerable to climate impacts and more active as "agents of change" in adaptation and mitigation (2010, p. 5). Through Plumwood's framework, this is not a paradox. It follows from the same dualism that creates this vulnerability. Those placed on the subordinated side of the nature/culture and feminine/masculine divide often develop practices that challenge mastery's one-sided approach.

Jacqui Patterson shows that women of "every color, every ethnicity, every part of the country" are affected by climate harms. This challenges the idea that valid knowledge requires avoiding lived experience. Patterson's examples show the value of situated and relational knowledge. Crichton's positivist approach, however, dismisses this kind of evidence.

None of this requires including academic studies on vulnerability as a separate argument added to literary readings. Its role here is narrower and more precise. It shows that the contrast between Robinson's relational epistemology and Crichton's *mastery* standpoint is not only fictional or formal. It also reflects a documented distinction regarding how climate knowledge and action are structured. This gives the ecofeminist reading a broader meaning beyond literary interpretation.

CONCLUSION

Read together, *Forty Signs of Rain* and *State of Fear* present more than a debate about the reality of climate change. They also explore how urgently it requires a response. They present two very different ways of understanding knowledge. Robinson's novel presents climate knowledge as relational. It develops through marriage, parenthood, cross-cultural relationships, and shared political work. In this way, the novel challenges the separation of reason from nature. It also challenges the separation of masculine authority from feminine care that is called the *mastery*. Crichton's novel, on the other hand, presents the standpoint of *mastery* clearly. It values technical expertise, and dismisses activist and emotional knowledge as irrational and dangerous. It also presents science as pure and separate from politics.

This is why Christopher Maughan describes *State of Fear* as "a distinctly reactionary narrative that tells us change is impossible" (2013, p. 54). Robinson argues that addressing climate change requires abandoning "some kind of free-market religion" (2004, p. 290). These are not simply opposing political views, they also reflect two different ways of understanding knowledge. The difference between the two texts goes beyond their political views; it also lies in their differing perspectives on knowledge. An ecofeminist reading reveals that these views on knowledge are also linked to gender. Recognizing women as potential contributors to climate solutions, along with their vulnerability to climate change, is more than simply a goal of climate policy. Within this article's framework, this idea challenges the belief that environmental knowledge and solutions should be controlled by those who claim expert authority. It supports the relational approach to knowledge that Robinson's fiction already models. Read this way, climate fiction goes beyond depicting climate politics. The contrast between these novels shows how the genre presents competing ways of understanding climate knowledge.

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FROM PHYTOCHEMICAL CHARACTERIZATION TO FUNCTIONAL FOOD APPLICATIONS: A SYSTEMATIC REVIEW OF DANDELION (TARAXACUM OFFİCİNALE) RESEARCH IN FOOD SCIENCE

FİTOKİMYASAL KARAKTERİZASYONDAN FONKSİYONEL GIDA UYGULAMALARINA: GIDA BİLİMİNDE KARAHİNDİBA (TARAXACUM OFFİCİNALE) ARAŞTIRMALARININ SİSTEMATİK DERLEMESİ

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ÖZET
Karahindiba *(Taraxacum officinale L.),* vitaminler, mineraller, fenolik bileşikler, flavonoidler gibi biyoaktif bileşenler açısından zengin olup iyi bir prebiyotik kaynağı olmasına rağmen yeterince değerlendirilmeyen yenilebilir bir bitkidir. Son on yılda, araştırmalar giderek fonksiyonel gıdalardaki kullanımına odaklanmıştır; ancak, işleme teknolojileri, ürün uygulamaları ve duyusal sınırlamalarla ilgili çalışmalar yetersiz kalmaktadır. Bu kapsam derlemesinin amacı, 2016–2026 yılları arasında *Taraxacum officinale* üzerine gıda bilimi ve teknolojisi alanında yayımlanan araştırmaları sistematik biçimde haritalamak; kullanılan bitki kısımlarını, işleme teknolojilerini, geliştirilen gıda ürünlerini, incelenen kalite özelliklerini ve son 10 yıldaki araştırma eğilimlerini belirlemek ve gelecekteki çalışmalar için araştırma boşluklarını ortaya koymaktır. Web of Science ve Scopus veri tabanlarında "*Taraxacum officinale*", "karahindiba", "gıda işleme teknolojileri", "gıda ürünü", "fitokimyasal özellik", "fonksiyonel gıda", "duyusal", "biyoerişilebilirlik" ve "depolama" terimlerinin kombinasyonları kullanılarak arama yapılmıştır. Veriler yayın yılı, ülke, bitki kısmı, işleme yöntemi, gıda matrisi, analizler, temel bulgular ve bildirilen sınırlamalara göre listelenmiştir. Araştırma, fitokimyasal karakterizasyondan ekstraksiyona, enkapsülasyona, fermantasyona, doğrudan gıdaya katılıma, yeşil ekstraksiyona, nanoenkapsülasyona, prebiyotik işlevselliğe ve sürdürülebilir ürün geliştirmeye doğru evrilmiştir. Karahindiba genel olarak fenolik içeriği ve antioksidan kapasitesini artırsa da, daha yüksek katılım seviyeleri acılık, renk, doku veya duyusal kabul edilebilirlikte istenmeyen değişikliklere neden olabilmektedir. Karahindiba, fonksiyonel ve sürdürülebilir bir gıda bileşeni olarak önemli bir potansiyele sahiptir. Bununla birlikte duyusal kabul, raf ömrü, hammadde standardizasyonu, pestisit/ağır metal güvenliği ve in vitro sindirim sonrası biyoerişilebilirlik halen başlıca araştırma boşluklarıdır.
Anahtar Kelimeler: Karahindiba (*Taraxacum officinale*), gıda işleme teknolojileri, duyusal, fonksiyonel gıda, fitokimyasal özellikler, biyoerişilebilirlik, depolama.

ABSTRACT
Dandelion (*Taraxacum officinale)* is an edible plant that is rich in bioactive components such as vitamins, minerals, phenolic compounds, and flavonoids, and although it is a beneficial source of prebiotics, it is not sufficiently appreciated. In the last decade, research has increasingly focused on its use in functional foods; however, studies related to processing technologies, product applications, and sensory limitations remain insufficient. This systematic review aimed to systematically map food science and technology studies on *Taraxacum officinale* published between 2016 and 2026, identify the plant parts, processing technologies, food matrices and quality characteristics investigated, evaluate the evolution of research trends, and highlight knowledge gaps for future functional food applications. Searches were conducted in the Web of Science and Scopus databases using combinations of the terms "*Taraxacum officinale*," "dandelion," "food processing technologies," "food product," "phytochemical properties," "functional food," "sensory," "bioaccessibility," and "storage." The study presents the data by year of publication, country, plant part, processing method, food matrix, analyses, key findings, and reported limitations. The study presents the data by year of publication, country, plant part, processing method, food matrix, analyses, key findings, and reported limitations. The research has ranged from phytochemical characterisation, extraction, encapsulation, fermentation, direct food usage, green extraction, nanoencapsulation, and prebiotic activity to sustainable product development.

Dandelion generally enhances phenolic content and antioxidant capacity, but higher levels of incorporation may induce undesirable changes in bitterness, colour, texture, or sensory acceptability. Dandelion is a very promising functional and sustainable food ingredient. However, major research gaps still exist in sensory acceptance, shelf life, standardisation of raw material, safety of pesticide/heavy metal, and in vitro post-digestion bioavailability.
Keywords: Dandelion, (*Taraxacum officinale*), food processing technologies, sensory, functional food, phytochemical, bioaccessibility, storage.

IMPACTS OF CLIMATE CHANGE ON FRUIT GROWING AND SUSTAINABLE PRODUCTION APPROACHES

İKLİM DEĞİŞİKLİĞİNİN MEYVECİLİK ÜZERİNDEKİ ETKİLERİ VE SÜRDÜRÜLEBİLİR ÜRETİM YAKLAŞIMLARI

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ÖZET
İklim değişikliği, son yıllarda tarımsal üretim sistemlerini etkileyen en önemli küresel çevre sorunlarından biri haline gelmiştir. Uzun ömürlü bitkileri ve uzun üretim döngüleri nedeniyle meyve yetiştiriciliği sektörü, iklim değişikliğinin olumsuz etkilerine en duyarlı tarımsal faaliyetlerden biridir. Küresel sıcaklık artışı, yağış düzenlerindeki düzensizlikler, kuraklık, sıcak hava dalgaları, geç ilkbahar donları ve aşırı meteorolojik olaylar, çiçeklenme zamanı, meyve tutumu, verim, kalite ve depolama performansında önemli değişikliklere neden olmaktadır. Aynı zamanda, zararlı ve hastalıkların dağılım alanları genişlemekte, su kaynakları üzerindeki baskı artmakta ve üretim maliyetleri yükselmektedir. Bu çalışma, iklim değişikliğinin meyve yetiştiriciliği üzerindeki başlıca etkilerini değerlendirmekte; sürdürülebilir meyve üretimine uygulanabilir uyum stratejileri, su yönetimi, toprak koruma uygulamaları, uygun çeşit ve anaç seçimi, biyoteknolojik gelişmeler, hassas tarım teknolojileri ve dijital uygulamalar mevcut literatür ışığında tartışılmaktadır. Ayrıca, karbon ayak izini azaltmak, doğal kaynakları korumak ve iklim değişikliğine dayanıklı üretim sistemleri geliştirmek için öneriler sunulmaktadır. Sonuç olarak, sürdürülebilir meyve tarımı uygulamalarının yaygın olarak benimsenmesi, yalnızca üretim miktarını korumakla kalmayacak, aynı zamanda çevresel, ekonomik ve sosyal sürdürülebilirliği de destekleyecektir.
Anahtar Kelimeler: İklim değişikliği, sürdürülebilir meyve tarımı, kuraklık, hassas tarım, meyve kalitesi, adaptasyon.

ABSTRACT
Climate change has become one of the most significant global environmental problems affecting agricultural production systems in recent years. Due to its long lifespan and extended production cycles, the fruit growing sector is one of the agricultural activities most sensitive to the negative impacts of climate change. Global temperature increase, irregularities in rainfall patterns, drought, heat waves, late spring frosts, and extreme meteorological events are causing significant changes in flowering time, fruit set, yield, quality, and storage performance. Simultaneously, the distribution areas of pests and diseases are expanding, pressure on water resources is increasing, and production costs are rising. This study evaluates the main impacts of climate change on fruit growing; applicable adaptation strategies for sustainable fruit production, water management, soil conservation practices, appropriate variety and rootstock selection, biotechnological advancements, precision agriculture technologies, and digital applications are discussed in light of the existing literature. Furthermore, recommendations are presented to reduce carbon footprint, conserve natural resources, and develop climate change-resilient production systems. In conclusion, the widespread adoption of sustainable fruit farming practices will not only maintain production quantity but also support environmental, economic, and social sustainability.
Keywords: Climate change, sustainable fruit farming, drought, precision agriculture, fruit quality, adaptation.

1. Giriş

Tarımsal üretim, insanlığın temel gıda gereksiniminin karşılanmasında stratejik öneme sahip sektörlerden biridir. Son yıllarda küresel iklim sisteminde meydana gelen değişiklikler, tarımsal üretimin sürdürülebilirliğini tehdit eden en önemli çevresel faktörlerden biri olarak kabul edilmektedir. Sanayi Devrimi sonrasında atmosferde sera gazı konsantrasyonlarının hızla artması, küresel ortalama sıcaklıkların yükselmesine, yağış rejimlerinin değişmesine ve aşırı hava olaylarının daha sık görülmesine neden olmuştur. Özellikle son elli yılda gözlenen sıcaklık artışları, birçok tarımsal ekosistemde üretim desenlerini değiştirmiş ve tarımsal verimlilik üzerinde önemli baskılar oluşturmuştur. Meyvecilik sektörü, çok yıllık bitkilerden oluşması nedeniyle iklim değişikliğinden en fazla etkilenen tarımsal faaliyetlerden biridir. Tarla bitkilerinde yıllık üretim planlaması yapılabilirken, meyve bahçeleri uzun yıllar boyunca aynı alanda üretime devam ettiğinden iklimsel değişimlere uyum sağlamak daha güç olmaktadır. Meyve türlerinin büyük çoğunluğu belirli sıcaklık, yağış, nem ve soğuklama ihtiyacı koşullarında optimum gelişme göstermektedir. Bu koşulların değişmesi; fenolojik gelişim dönemlerini, çiçeklenme zamanını, döllenmeyi, meyve tutumunu ve kalite parametrelerini doğrudan etkilemektedir. Jing ve ark., 2024; Yang ve ark., 2024

Küresel iklim değişikliği yalnızca sıcaklık artışıyla sınırlı değildir. Kuraklık süresinin uzaması, düzensiz yağışlar, ani dolu olayları, sıcak hava dalgaları, geç ilkbahar donları ve kuvvetli rüzgârlar da meyvecilik açısından önemli riskler oluşturmaktadır. Özellikle Akdeniz Havzası, iklim değişikliğinden en fazla etkilenmesi beklenen bölgeler arasında yer almakta olup, Türkiye de bu bölgenin önemli bir parçasıdır. Türkiye; elma, kiraz, kayısı, incir, nar, üzüm, fındık, antepfıstığı ve zeytin gibi birçok meyve türünde dünyanın önde gelen üretici ülkeleri arasında bulunmaktadır. Bu nedenle iklim değişikliğinin ülke meyveciliği üzerindeki etkilerinin belirlenmesi ve uygun uyum stratejilerinin geliştirilmesi büyük önem taşımaktadır. (Chackar ve ark., 2023)

Son yıllarda yapılan araştırmalar, ortalama sıcaklıklardaki her 1 °C'lik artışın birçok meyve türünde fenolojik gelişimi 5–10 gün öne çekebildiğini göstermektedir. Erken çiçeklenme ise geç ilkbahar donlarına yakalanma riskini artırmakta ve önemli verim kayıplarına neden olabilmektedir. Bunun yanında yüksek sıcaklıklar fotosentez etkinliğini azaltmakta, su tüketimini artırmakta, meyve iriliğini küçültmekte ve kalite özelliklerinde bozulmalara yol açmaktadır. Aynı zamanda su kaynaklarının azalması, sulama maliyetlerini yükselterek üretimin ekonomik sürdürülebilirliğini de olumsuz etkilemektedir. (Francini, ve Sebastiani, 2019; Hasegawa ve ark., 2021;

İklim değişikliğinin olumsuz etkilerinin azaltılabilmesi için sürdürülebilir üretim sistemlerinin geliştirilmesi zorunlu hale gelmiştir. Sürdürülebilir meyvecilik; doğal kaynakların korunmasını, su ve enerji kullanımının optimize edilmesini, biyolojik çeşitliliğin desteklenmesini ve çevresel etkilerin azaltılmasını amaçlayan bütüncül bir üretim yaklaşımıdır. Bu kapsamda damla sulama sistemleri, örtü bitkileri, organik madde yönetimi, uygun anaç ve çeşit seçimi, biyolojik mücadele, dijital tarım uygulamaları ve hassas tarım teknolojileri giderek daha fazla önem kazanmaktadır. Ayrıca yapay zekâ destekli karar sistemleri, uzaktan algılama teknolojileri ve sensör tabanlı izleme sistemleri sayesinde üretim süreçleri daha etkin yönetilebilmekte, kaynak kullanımı optimize edilmekte ve iklim risklerine karşı daha dirençli üretim modelleri geliştirilebilmektedir. Prasad ve ark., 2023; Hossain ve ark., 2024

Bu derleme çalışmasının amacı, iklim değişikliğinin meyvecilik sektörü üzerindeki başlıca etkilerini güncel bilimsel veriler ışığında değerlendirmek ve sürdürülebilir meyve üretimi için uygulanabilecek temel adaptasyon stratejilerini ortaya koymaktır. Ayrıca gelecekte iklim değişikliğine dayanıklı meyvecilik sistemlerinin geliştirilmesine katkı sağlayabilecek teknolojik ve yönetsel yaklaşımlar ele alınarak sektör için uygulanabilir öneriler sunulmuştur.

2. İklim Değişikliğinin Meyvecilik Üzerindeki Etkileri

İklim değişikliği, sıcaklık artışı, yağış rejimlerindeki düzensizlikler, atmosferik karbondioksit (CO_2) konsantrasyonundaki yükselme ve ekstrem meteorolojik olayların sıklığındaki artış ile karakterize edilen küresel bir süreçtir. Tarımsal üretim sistemleri içerisinde meyvecilik, çok yıllık bitkilerden oluşması nedeniyle bu değişimlerden en fazla etkilenen sektörlerden biri olarak değerlendirilmektedir. Meyve ağaçlarının ekonomik ömrünün uzun olması, bahçelerin kısa sürede başka bölgelere taşınamaması ve fenolojik gelişimlerinin iklim koşullarına yüksek derecede bağımlı olması, sektörü iklim değişikliğine karşı daha kırılgan hale getirmektedir (IPCC, 2023).

Son yıllarda küresel ortalama sıcaklığın sanayi öncesi döneme göre yaklaşık 1,1 °C artmış olması, meyve yetiştiriciliğinde üretim takvimini önemli ölçüde değiştirmiştir. Sıcaklık artışı yalnızca bitkilerin büyümesini hızlandırmakla kalmamakta; aynı zamanda çiçeklenme zamanı, meyve tutumu, olgunlaşma süresi, verim ve kalite özellikleri üzerinde de belirleyici rol oynamaktadır. Özellikle ılıman iklim meyve türlerinde sıcaklık artışına bağlı olarak fenolojik evrelerin daha erken gerçekleştiği bildirilmektedir.

2.1. Artan Sıcaklıkların Meyve Ağaçları Üzerindeki Etkileri

Sıcaklık, meyve ağaçlarının fizyolojik faaliyetlerini kontrol eden en önemli çevresel faktörlerden biridir. Fotosentez, solunum, enzim aktivitesi, su tüketimi ve karbon metabolizması doğrudan sıcaklıktan etkilenmektedir. Optimum sıcaklık değerlerinin üzerine çıkılması durumunda fotosentetik etkinlik azalırken, solunum hızının artması nedeniyle bitkinin enerji dengesi bozulmaktadır. Bunun sonucunda vegetatif gelişme zayıflamakta, meyve iriliği küçülmekte ve verim düşmektedir. Yüksek sıcaklıklar özellikle elma, armut, kiraz, şeftali ve kayısı gibi ılıman iklim meyve türlerinde güneş yanıklığı, kabuk renklenmesinde bozulma, meyve eti sertliğinde azalma ve depolama ömrünün kısalması gibi kalite kayıplarına neden olmaktadır. Narenciye türlerinde ise aşırı sıcaklıklar meyve kabuğunda çatlama, su kaybı ve erken olgunlaşma gibi sorunlara yol açmaktadır. Antepfıstığı, zeytin ve badem gibi kuraklığa daha dayanıklı türlerde bile uzun süreli sıcak hava dalgaları fotosentezin baskılanmasına ve meyve dolgunluğunun azalmasına neden olmaktadır. Szymańska ve ark., 2017; li ve ark., 2023; Abasi ve ark., 2025;

Yapılan çalışmalar, sıcaklık artışının yalnızca mevcut üretim sezonunu değil, bir sonraki yılın çiçek tomurcuğu oluşumunu da etkileyerek alternatif ürün verme eğilimini artırabileceğini göstermektedir. Bu durum özellikle antepfıstığı ve zeytin gibi periyodisite eğilimi gösteren türlerde daha belirgin olarak ortaya çıkmaktadır.

2.2. Kuraklık ve Su Stresinin Etkileri

Küresel iklim değişikliğinin en önemli sonuçlarından biri su kaynaklarının azalmasıdır. Yağış miktarındaki azalma ve buharlaşmanın artması, meyve bahçelerinde su stresinin daha sık görülmesine neden olmaktadır. Kuraklık, bitkide stomaların kapanmasına yol açarak fotosentez hızını düşürmekte ve karbon asimilasyonunu sınırlandırmaktadır. Uzun süreli su stresi sonucunda sürgün gelişimi zayıflamakta, yaprak alanı küçülmekte ve meyve gelişimi olumsuz etkilenmektedir. Su yetersizliği özellikle meyve iriliği üzerinde önemli kayıplara neden olmaktadır. Bunun yanında çözünebilir kuru madde miktarında artış görülmesine rağmen toplam verim düşmektedir. Şiddetli kuraklık koşullarında ise meyve dökümü artmakta, çiçek tomurcuğu oluşumu azalmakta ve gelecek yılın verimi de olumsuz etkilenmektedir. (Tsiupka ve ark., 2023; Zhang ve ark., 2023; Mihaljević,ve ark., 2025)

Akdeniz Havzası'nda yer alan Türkiye için yapılan iklim projeksiyonları, özellikle yaz aylarında yağışların azalacağını ve kuraklık riskinin artacağını göstermektedir. Bu nedenle sulama suyunun etkin kullanımı ve kuraklığa dayanıklı anaçların geliştirilmesi gelecekte sürdürülebilir meyveciliğin temel bileşenleri arasında yer alacaktır.

2.3. Soğuklama İhtiyacındaki Değişimler

Ilıman iklim meyve türlerinin büyük çoğunluğu normal tomurcuk uyanması ve düzenli çiçeklenme gerçekleştirebilmek için belirli miktarda kış soğuklamasına ihtiyaç duymaktadır. Soğuklama gereksiniminin yeterince karşılanamaması durumunda düzensiz tomurcuk patlaması, zayıf çiçeklenme, düşük meyve tutumu ve önemli verim kayıpları meydana gelmektedir. Küresel sıcaklık artışları nedeniyle birçok bölgede kış aylarında biriken soğuklama süresinin giderek azaldığı bildirilmektedir. Özellikle elma, kiraz, şeftali, armut ve ceviz gibi yüksek soğuklama gereksinimi bulunan türlerde bu durum önemli üretim sorunlarına neden olmaktadır. Araştırmalar, sıcak geçen kışların ardından çiçeklenmenin düzensiz gerçekleştiğini ve hasat döneminin uzadığını göstermektedir. Francini, ve Sebastiani 2019; Salama ve ark., 2021

Soğuklama yetersizliği yalnızca verimi azaltmakla kalmamakta, meyve iriliği, renk oluşumu ve meyve kalitesini de olumsuz yönde etkilemektedir. Bu nedenle gelecekte düşük soğuklama gereksinimine sahip yeni çeşitlerin geliştirilmesi ve uygun anaç kullanımının yaygınlaştırılması önem kazanacaktır.

2.4. Fenolojik Kaymalar

İklim değişikliği ile birlikte meyve türlerinin fenolojik gelişim dönemlerinde önemli değişimler meydana gelmektedir.

İlkbahar sıcaklıklarının erken yükselmesi tomurcuk patlaması, çiçeklenme ve meyve gelişim dönemlerinin normalden daha erken başlamasına neden olmaktadır. Erken çiçeklenme ilk bakışta olumlu gibi görünse de geç ilkbahar donlarına yakalanma riskini önemli ölçüde artırmaktadır. Özellikle kayısı, badem, kiraz ve erik gibi erken çiçeklenen türlerde birkaç saat süren don olayları bile ürünün büyük bölümünün kaybedilmesine neden olabilmektedir. Ayrıca çiçeklenme döneminin değişmesi, tozlayıcı böceklerin aktivitesi ile bitki fenolojisi arasındaki senkronizasyonu ve bozarak döllenme başarısını da azaltabilmektedir. (Chmielewski, ve ark., 2004; Schmitt ve ark., 2022)
Fenolojik kaymalar hasat tarihlerini de değiştirmekte; bazı türlerde hasat birkaç hafta erkene çekilirken, bazılarında olgunlaşma sürecinde düzensizlikler meydana gelmektedir. Bu durum pazarlama planlamasını, depolama süreçlerini ve ihracat takvimini doğrudan etkilemektedir.

2.5. Zararlı ve Hastalık Popülasyonlarındaki Değişimler

Artan sıcaklıklar ve değişen iklim koşulları yalnızca bitkileri değil, zararlı böcekler ve bitki hastalıklarını da etkilemektedir. Daha sıcak geçen kış ayları zararlıların kışlama başarısını artırırken, yıl içerisindeki döl sayısının yükselmesine neden olmaktadır. Bunun sonucunda pest popülasyonlarında önemli artışlar meydana gelmekte ve mücadele maliyetleri yükselmektedir. Benzer şekilde mantari hastalıklar, bakteriyel enfeksiyonlar ve bazı viral hastalıkların yayılış alanları genişlemektedir. İklim değişikliği aynı zamanda yeni zararlı türlerin farklı bölgelere taşınmasını kolaylaştırmakta ve biyolojik mücadele dengesini değiştirmektedir. Bu durum pestisit kullanımının artmasına ve çevresel sürdürülebilirlik açısından yeni risklerin ortaya çıkmasına neden olmaktadır (Cosmulescu ve ark., 2026)

2.6. Meyve Kalitesi Üzerindeki Etkiler

İklim değişikliği yalnızca verim üzerinde değil, meyvelerin ticari kalite özellikleri üzerinde de önemli değişikliklere yol açmaktadır. Yüksek sıcaklıklar ve su stresi meyve ağırlığında azalma, kabuk renginde bozulma, meyve eti sertliğinin düşmesi ve raf ömrünün kısalması gibi olumsuzluklara neden olabilmektedir. Ayrıca organik asitler, çözünebilir şekerler, fenolik bileşikler ve antioksidan içerikleri de çevresel koşullardan önemli ölçüde etkilenmektedir. Bazı araştırmalar, hafif düzeyde su stresinin üzüm ve nar gibi türlerde fenolik bileşik birikimini artırabileceğini göstermesine karşın, uzun süreli ve şiddetli kuraklığın hem verim hem de kaliteyi belirgin biçimde düşürdüğünü ortaya koymaktadır. Meyve kalitesindeki değişimler yalnızca tüketici tercihlerini değil, işleme sanayisinin hammadde kalitesini ve uluslararası ticarette rekabet gücünü de doğrudan etkilemektedir . Tagliavini ve ark., 2007; Cosmulescu ve ark., 2026

3. Sürdürülebilir Meyvecilik Uygulamaları ve İklim Değişikliğine Uyum Stratejileri

İklim değişikliğinin meyvecilik üzerindeki olumsuz etkilerinin azaltılabilmesi için yalnızca mevcut üretim tekniklerinin iyileştirilmesi yeterli değildir. Aynı zamanda çevresel, ekonomik ve sosyal sürdürülebilirliği birlikte ele alan bütüncül üretim sistemlerinin geliştirilmesi gerekmektedir. Bu kapsamda sürdürülebilir meyvecilik; doğal kaynakların korunmasını, su ve enerji kullanımının optimize edilmesini, karbon ayak izinin azaltılmasını ve biyolojik çeşitliliğin desteklenmesini amaçlayan üretim modeli olarak tanımlanmaktadır. Günümüzde iklim değişikliğine uyum sağlayabilen bahçe yönetim sistemlerinin oluşturulması, meyvecilik sektörünün geleceği açısından stratejik önem taşımaktadır (FAO, 2023).

3.1. Su Yönetimi ve Modern Sulama Sistemleri

Su kıtlığı, gelecekte meyvecilik sektörünün karşılaşacağı en önemli sorunlardan biridir. Bu nedenle sulama suyunun etkin kullanılması sürdürülebilir üretimin temel bileşenlerinden biridir. Damla sulama, mikro yağmurlama ve sensör tabanlı sulama sistemleri, geleneksel yöntemlere göre daha yüksek su kullanım etkinliği sağlamaktadır. Toprak nem sensörleri ve meteorolojik verilerin birlikte değerlendirilmesiyle yalnızca bitkinin ihtiyaç duyduğu kadar su verilmesi mümkün olmakta; böylece hem su tasarrufu sağlanmakta hem de enerji maliyetleri azaltılmaktadır. Kısıntılı sulama uygulamaları özellikle zeytin, üzüm, nar ve antepfıstığı gibi türlerde su tüketimini azaltırken meyve kalitesini koruyabilmektedir. Ancak bu uygulamaların tür, çeşit ve gelişme dönemine göre planlanması gerekmektedir (Wang, ve ark., 2019; Abasi ve ark., 2025)

3.2. Toprak Sağlığının Korunması

Sağlıklı topraklar, iklim değişikliğine dayanıklı meyvecilik sistemlerinin temelini oluşturmaktadır. Organik madde miktarının artırılması, kompost ve çiftlik gübresi kullanımı, yeşil gübreleme ve örtü bitkileri uygulamaları; su tutma kapasitesini artırmakta, erozyonu azaltmakta ve mikrobiyal aktiviteyi desteklemektedir. Rejeneratif tarım yaklaşımları, karbonun toprakta depolanmasını teşvik ederek hem sera gazı emisyonlarının azaltılmasına hem de toprak verimliliğinin artırılmasına katkı sağlamaktadır. Özellikle meyve bahçelerinde örtü bitkilerinin kullanılması, yağış sularının infiltrasyonunu artırmakta ve yüzey akışını azaltmaktadır. Tagliavini ve ark., 2007; Srivastava ve ark., 2021

3.3. İklime Dayanıklı Çeşit ve Anaç Kullanımı

İklim değişikliğine uyumun en etkili yollarından biri, yüksek sıcaklık ve kuraklığa dayanıklı çeşit ve anaçların geliştirilmesidir. Bitki ıslah programlarında yalnızca yüksek verim değil; su kullanım etkinliği, sıcaklık toleransı, tuzluluk dayanımı ve hastalıklara direnç gibi özellikler de ön plana çıkmaktadır. Özellikle düşük soğuklama gereksinimine sahip çeşitlerin geliştirilmesi, sıcak geçen kışların etkisinin azaltılmasında önemli bir çözüm olarak değerlendirilmektedir. Aynı zamanda derin kök sistemine sahip anaçlar kurak dönemlerde suya erişimi artırarak üretim güvenliğini desteklemektedir. (Babaei ve ark., 2025; Mezrioui ve ark., 2025; Mihaljević ve ark., 2025).

3.4. Entegre Zararlı Yönetimi

Artan sıcaklıklar nedeniyle zararlı ve hastalık baskısının yükselmesi, pestisit kullanımını artırma eğilimindedir. Bunun yerine biyolojik mücadele, feromon tuzakları, kültürel önlemler ve hassas izleme sistemlerini kapsayan Entegre Zararlı Yönetimi (IPM) uygulamaları hem çevresel etkileri azaltmakta hem de üretim maliyetlerini düşürmektedir. (Abasi ve ark., 2025)

3.5. Hassas Tarım ve Dijital Bahçe Yönetimi

Son yıllarda hassas tarım teknolojileri sürdürülebilir meyveciliğin en hızlı gelişen alanlarından biri olmuştur. Uydu görüntüleri, insansız hava araçları (drone), multispektral kameralar, yapay zekâ algoritmaları ve nesnelerin interneti (IoT) tabanlı sensör sistemleri sayesinde bahçeler gerçek zamanlı olarak izlenebilmektedir. (Güler, ve Kara 2005; Özgüven ve ark., 2023).

Bu teknolojiler sayesinde;

- Su stresi erken belirlenebilmekte,
- Hastalık belirtileri oluşmadan tespit edilebilmekte,
- Gübreleme değişken oranlı uygulanabilmekte,
- Hasat zamanı doğru planlanabilmektedir.

Bu uygulamalar hem üretim maliyetlerini azaltmakta hem de çevresel sürdürülebilirliği desteklemektedir.

4. Gelecek Perspektifleri ve Yeni Teknolojiler

İklim değişikliğinin etkilerinin önümüzdeki yıllarda daha da belirginleşeceği öngörülmektedir. Bu nedenle geleceğin meyveciliği, yalnızca klasik bahçe yönetimine değil; dijitalleşme, yapay zekâ ve biyoteknoloji temelli sistemlere dayanacaktır.

Yapay zekâ destekli karar destek sistemleri; meteorolojik veriler, toprak özellikleri ve bitki fizyolojik parametrelerini birlikte değerlendirerek sulama, gübreleme ve hastalık yönetiminde üreticilere anlık öneriler sunmaktadır. Ayrıca makine öğrenmesi algoritmaları, geçmiş yıllara ait iklim verilerini analiz ederek verim tahmini ve risk analizi yapılmasına olanak sağlamaktadır.

Uzaktan algılama teknolojileri ve drone sistemleri sayesinde meyve bahçeleri yüksek çözünürlüklü görüntülerle izlenebilmekte, bitki gelişimindeki farklılıklar erken dönemde belirlenebilmektedir. Robotik sistemlerin budama, yabancı ot kontrolü, ilaçlama ve hatta hassas tozlaşma uygulamalarında kullanılması iş gücü ihtiyacını azaltırken uygulama doğruluğunu artırmaktadır.

Genom düzenleme teknikleri ve moleküler ıslah yöntemleri de iklim değişikliğine dayanıklı yeni meyve çeşitlerinin geliştirilmesinde önemli rol oynayacaktır. CRISPR/Cas tabanlı genom düzenleme teknolojileriyle sıcaklık, kuraklık ve tuzluluk stresine tolerans sağlayan genlerin hedeflenmesi, gelecekte sürdürülebilir meyvecilik açısından önemli fırsatlar sunmaktadır.

Bunun yanında karbon nötr üretim sistemleri, yenilenebilir enerji kullanımı, döngüsel tarım uygulamaları ve iklim dostu bahçe yönetimi yaklaşımlarının yaygınlaşması beklenmektedir.

Böylece hem doğal kaynakların korunması hem de meyvecilik sektörünün uzun vadeli rekabet gücünün artırılması mümkün olacaktır.

5. Sonuç

İklim değişikliği, meyvecilik sektörünü üretimden hasat sonrasına kadar tüm aşamalarda etkileyen küresel bir olgu haline gelmiştir. Artan sıcaklıklar, düzensiz yağışlar, kuraklık, geç ilkbahar donları ve ekstrem hava olayları meyve verimi, kalite özellikleri ve üretim ekonomisi üzerinde önemli baskılar oluşturmaktadır. Aynı zamanda zararlı ve hastalık popülasyonlarının değişmesi, su kaynaklarının azalması ve toprak kalitesindeki bozulmalar mevcut üretim sistemlerinin sürdürülebilirliğini tehdit etmektedir.

Bu nedenle iklim değişikliğine uyum sağlayabilen sürdürülebilir meyvecilik uygulamalarının yaygınlaştırılması zorunlu hale gelmiştir. Su kullanım etkinliğinin artırılması, toprak sağlığının korunması, iklime dayanıklı çeşit ve anaçların geliştirilmesi, entegre zararlı yönetimi ile hassas tarım teknolojilerinin birlikte uygulanması, geleceğin üretim sistemlerinin temel bileşenleri olacaktır. Bunun yanında yapay zekâ, uzaktan algılama, robotik sistemler ve biyoteknolojik yeniliklerin meyvecilikte daha yaygın kullanılması, kaynak kullanımını optimize ederken üretim risklerini azaltacaktır.

Sonuç olarak, sürdürülebilir meyvecilik yalnızca iklim değişikliğine uyum sağlamanın değil; aynı zamanda gıda güvenliğinin korunması, doğal kaynakların sürdürülebilir yönetimi ve üretici gelirlerinin güvence altına alınmasının da temel araçlarından biridir. Araştırma kurumları, üniversiteler, kamu kuruluşları ve üreticiler arasında kurulacak güçlü iş birlikleri, iklim dirençli meyvecilik sistemlerinin geliştirilmesini hızlandıracaktır.

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SÜRDÜRÜLEBİLİR MEYVECİLİKTE AKILLI TARIM TEKNOLOJİLERİNİN İKLİM DEĞİŞİKLİĞİNE UYUM SÜRECİNDEKİ ROLÜ

THE ROLE OF SMART AGRICULTURE TECHNOLOGIES IN THE CLIMATE CHANGE ADAPTATION PROCESS OF SUSTAINABLE FRUIT PRODUCTION

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ÖZET
İklim değişikliği, tarımsal üretim sistemlerini doğrudan etkileyen en önemli küresel sorunlardan biridir ve özellikle uzun ömürlü bitkilerden oluşan meyve yetiştiriciliği sektörü bu değişikliklerden önemli ölçüde etkilenmektedir. Küresel sıcaklık artışı, yağış düzenlerindeki düzensizlikler, kuraklık, aşırı hava olayları ve biyotik stres faktörleri, meyve üretiminde verim, kalite ve ekonomik sürdürülebilirlik açısından ciddi riskler oluşturmaktadır. Bu süreçte, akıllı tarım teknolojileri, doğal kaynakların daha verimli kullanımını sağlayarak iklim değişikliğine uyum stratejilerinin temel bileşenlerinden biri haline gelmiştir. Nesnelerin İnterneti (IoT), küresel konumlandırma sistemleri (GPS), uzaktan algılama, insansız hava araçları (İHA), yapay zeka, makine öğrenimi ve büyük veri analitiği gibi dijital teknolojiler, hassas sulama, gübreleme, hastalık yönetimi ve hasat planlamasını mümkün kılmaktadır. Bu derlemede, akıllı tarım teknolojilerinin sürdürülebilir meyve yetiştiriciliğindeki uygulama alanları, iklim değişikliğine uyum sürecine katkıları ve gelecekteki uygulama potansiyelleri, güncel bilimsel çalışmalar doğrultusunda değerlendirilmiştir. Sonuç olarak, dijital teknolojilerin meyve yetiştiriciliği sektörüne entegrasyonunun kaynak kullanım verimliliğini artırdığı, çevresel etkileri azalttığı ve üretim sistemlerinin iklim değişikliğine karşı direncini güçlendirdiği belirlenmiştir.
Anahtar Kelimeler: Akıllı tarım, sürdürülebilir meyvecilik, iklim değişikliği, hassas tarım, yapay zekâ, dijital tarım.

ABSTRACT
Climate change is one of the most significant global problems directly affecting agricultural production systems, and the fruit growing sector, particularly consisting of perennial plants, is significantly impacted by these changes. Global temperature increase, irregularities in rainfall patterns, drought, extreme weather events, and biotic stress factors pose serious risks to yield, quality, and economic sustainability in fruit production. In this process, smart agriculture technologies have become a fundamental component of climate change adaptation strategies by enabling more efficient use of natural resources. Digital technologies such as the Internet of Things (IoT), global positioning systems (GPS), remote sensing, unmanned aerial vehicles (UAVs), artificial intelligence, machine learning, and big data analytics enable precision irrigation, fertilization, disease management, and harvest planning. This review evaluates the application areas of smart agriculture technologies in sustainable fruit growing, their contributions to the climate change adaptation process, and their future application potential in line with current scientific studies. As a result, it has been determined that the integration of digital technologies into the fruit growing sector increases resource use efficiency, reduces environmental impacts, and strengthens the resilience of production systems to climate change.
Keywords: Smart agriculture, sustainable fruit production, climate change, precision agriculture, artificial intelligence, digital farming.

1. Giriş
Son yıllarda küresel ölçekte yaşanan iklim değişikliği, tarım sektörünü doğrudan etkileyen en önemli çevre sorunlarından biri olarak kabul edilmektedir. Atmosferdeki sera gazı konsantrasyonlarının artması nedeniyle küresel ortalama sıcaklıkların yükselmesi, yağış düzenlerindeki değişiklikler, şiddetlenen kuraklıklar ve daha sık görülen aşırı hava olayları, ürün üretiminin sürdürülebilirliği üzerinde önemli bir baskı oluşturmaktadır (Hükümetlerarası İklim Değişikliği Paneli, 2023). Meyve yetiştiriciliği sektörü, özellikle çok yıllık bitkiler, uzun üretim döngüsü ve iklim koşullarına yüksek bağımlılığı nedeniyle bu değişikliklerden en çok etkilenen tarımsal üretim alanlarından biridir. Türkiye, çeşitli ekolojik bölgeleri sayesinde dünya meyve üretiminde önemli bir konuma sahiptir.

Elma, kiraz, kayısı, şeftali, nar, üzüm, fındık, zeytin ve fıstık gibi ekonomik olarak değerli birçok meyve türü ülkemizde geniş alanlarda yetiştirilmektedir. Ancak son zamanlarda yaşanan sıcaklık artışları, düzensiz yağışlar, geç bahar donları, dolu olayları ve uzun süreli kuraklıklar, meyve yetiştiriciliği sektöründe hem verim hem de kalite kayıplarına neden olmaktadır. Ayrıca, zararlıların ve hastalıkların yayılmasının genişlemesi, üretim maliyetlerindeki artış ve su kaynakları üzerindeki baskının yükselmesi, sürdürülebilir üretim için yeni çözümler arayışını zorunlu kılmıştır (Gıda ve Tarım Örgütü [FAO], 2023; Greco ve ark., 2025).

Sürdürülebilir meyve yetiştiriciliği, doğal kaynakları korumayı, çevresel etkileri azaltmayı, ekonomik verimliliği sürdürmeyi ve gelecek nesiller için üretim kapasitesini güvence altına almayı amaçlayan bütüncül bir üretim yaklaşımıdır. Bu yaklaşım içinde, verimli su kullanımı, toprak sağlığının korunması, biyoçeşitliliğin desteklenmesi ve enerji verimliliğinin artırılması temel hedefler arasındadır. Bununla birlikte, geleneksel üretim yöntemleri, iklim değişikliğinin neden olduğu hızlı değişimlere tek başlarına uyum sağlamak için yetersizdir. Bu nedenle, dijital dönüşüm ve akıllı tarım uygulamaları, sürdürülebilir üretim sistemlerinin geliştirilmesinde stratejik öneme sahiptir (Wolfert vd., 2017).

Akıllı tarım, bilgi ve iletişim teknolojilerini tarımsal üretime entegre ederek karar alma süreçlerini destekleyen modern bir üretim modelidir. Nesnelerin İnterneti (IoT), küresel konumlandırma sistemleri (GPS), coğrafi bilgi sistemleri (GIS), uzaktan algılama, insansız hava araçları (İHA), yapay zeka, makine öğrenimi ve büyük veri analitiği gibi teknolojiler, üretim alanlarından gerçek zamanlı verilerin elde edilmesini ve bu verilere dayanarak sulama, gübreleme, zararlı kontrolü ve hasat planlamasının daha hassas bir şekilde yapılmasını mümkün kılmaktadır (Basso & Antle, 2020).

Meyve yetiştiriciliğinde akıllı tarım teknolojilerinin kullanımı sadece verimi artırmakla kalmaz, aynı zamanda su ve gübre kullanım verimliliğini iyileştirir, pestisit tüketimini azaltır ve sera gazı emisyonlarının azaltılmasına katkıda bulunur. Özellikle sensör tabanlı sulama sistemleri, çok spektrumlu görüntüleme teknolojileri ve yapay zeka destekli hastalık teşhis sistemleri sayesinde üreticiler, iklim değişikliğinin neden olduğu stres faktörlerini erken tespit edebilir ve gerekli müdahaleleri zamanında yapabilir (Zhang vd., 2021).

Son yıllarda geliştirilen dijital karar destek sistemleri, üreticilere optimum sulama zamanı, hastalık riski, besin eksiklikleri ve hasat dönemi konusunda öneriler sunmak için meteorolojik verileri ve bitki fizyolojik parametrelerini birlikte analiz eder. Bu, kaynak kullanımını optimize eder, üretim maliyetlerini düşürür ve çevresel sürdürülebilirliği destekler. Ayrıca, yapay zeka tabanlı tahmin modelleri gelecekteki iklim risklerini öngörebilir ve daha etkili adaptasyon stratejilerine olanak tanır.

Akıllı tarım teknolojilerinin yaygın olarak benimsenmesi, sadece büyük ölçekli işletmeler için değil, küçük ve orta ölçekli üreticiler için de önemli fırsatlar sunmaktadır. Düşük maliyetli sensör sistemleri, mobil uygulamalar ve bulut tabanlı veri platformları, üreticilerin karar alma süreçlerini bilimsel verilere dayandırmalarını ve iklim değişikliğine karşı daha dirençli üretim sistemleri oluşturmalarını sağlamaktadır. Bununla birlikte, dijital altyapının güçlendirilmesi, üreticilerin teknik eğitimle desteklenmesi ve kamu-üniversite-özel sektör işbirliklerinin geliştirilmesi, bu teknolojilerin etkin kullanımı için çok önemlidir. Bu incelemenin amacı, akıllı tarım teknolojilerinin sürdürülebilir meyve yetiştiriciliğindeki uygulama alanlarını ortaya çıkarmak, bu teknolojilerin iklim değişikliğine uyum sürecine katkılarını değerlendirmek ve mevcut bilimsel literatüre uygun olarak gelecekte uygulanabilecek yenilikçi yaklaşımları incelemektir.

3.Akıllı Tarım Teknolojilerinin İklim Değişikliğine Uyum Sürecindeki Rolü ve Gelecek Perspektifleri

İklim değişikliği sadece sıcaklık artışına neden olan çevresel bir olgu değil, aynı zamanda tarımsal üretim sistemlerini yeniden şekillendiren küresel bir süreçtir. Uzun ömürlü bitkilere bağımlılığı nedeniyle meyve yetiştiriciliği sektörü, bu değişikliklere hızla uyum sağlayamayan üretim sistemleri arasındadır. Bu nedenle, sürdürülebilir meyve yetiştiriciliğinde iklim değişikliğine uyum, sadece çeşit ve anaç seçimiyle sınırlı olmayıp, dijital teknolojilerin üretim süreçlerine entegrasyonunu da içermektedir. Günümüzde akıllı tarım teknolojileri, üreticilerin iklim risklerini önceden tahmin etmelerini, kaynak kullanımını optimize etmelerini ve üretim kararlarını bilimsel verilere dayandırmalarını sağlamaktadır.

Yapay zeka, Nesnelerin İnterneti (IoT), uzaktan algılama, büyük veri analizi ve karar destek sistemleri, iklim değişikliğine dayanıklı meyve yetiştiriciliği sistemlerinin geliştirilmesinde temel araçlar olarak kabul edilmektedir (Lykas, ve Vagelas, 2023; Chaudhary vd., 2025).

3.1. Erken Uyarı ve Karar Destek Sistemleri

İklim değişikliğinin meyve yetiştiriciliği üzerindeki en önemli etkilerinden biri, aşırı hava olaylarının sıklığının ve şiddetinin artmasıdır. Geç bahar donları, sıcak hava dalgaları, dolu, aşırı yağış ve kuraklık gibi olaylar üretimde ciddi ekonomik kayıplara neden olmaktadır. Bu nedenle, gerçek zamanlı meteorolojik verileri analiz eden karar destek sistemleri, üreticilere önleyici tedbirler alma fırsatı sunmaktadır. Akıllı meteoroloji istasyonlarından elde edilen sıcaklık, bağıl nem, rüzgar hızı, güneş radyasyonu ve yağış verileri, yapay zeka algoritmaları tarafından analiz edilerek don riski, hastalık gelişimi ve sulama ihtiyaçları önceden tahmin edilmektedir. Böylece üreticiler, don kontrol sistemlerini zamanında devreye sokabilir, sulama programlarını optimize edebilir ve pestisitleri yalnızca gerektiğinde uygulayabilirler. Bu hem ekonomik kayıpları azaltır hem de çevresel sürdürülebilirliği destekler. (Das vd., 2023; Thirumagal vd., 2023)

3.2. Yapay Zekâ ile İklim Risklerinin Tahmini

Makine öğrenimi ve derin öğrenme algoritmaları, geçmiş iklim verilerini mevcut çevresel parametrelerle birlikte analiz ederek üretim sezonu için tahminler üretebilir. Özellikle, sıcaklık eğilimleri, yağış düzenleri ve toprak nemi gibi değişkenleri birlikte değerlendirerek, kuraklık riski, çiçeklenme zamanı ve hasat tarihleri yüksek doğrulukla tahmin edilebilir.

Yapay zeka tabanlı modeller ayrıca hastalık ve zararlı popülasyonlarının gelişimini de tahmin edebilir. Örneğin, elma uyuzu, asma mildiyosu ve turunçgil hastalıkları gibi birçok patojen için geliştirilen tahmin modelleri, uygun çevresel koşullar ortaya çıkmadan önce üreticileri uyarabilir. Bu, pestisit kullanımını azaltır, daha etkili biyolojik kontrolü sağlar ve çevresel yükü düşürür (Kutyrev vd., 2022; Das vd., 2023).

3.3. Kaynak Kullanım Etkinliğinin Artırılması

İklim değişikliğinin su kaynaklarında azalmaya ve enerji maliyetlerinde artışa yol açmasıyla birlikte, üretimde kaynak verimliliği daha da önem kazanmıştır. Akıllı tarım sistemleri, sensörler, otomasyon yazılımları ve değişken oranlı uygulama teknolojileri sayesinde, su, gübre ve bitki koruma ürünlerinin yalnızca gerekli miktarlarda kullanılmasını sağlar. Özellikle değişken oranlı gübreleme sistemleri, toprak analizi ve bitki beslenme durumuna bağlı olarak farklı bölgelerde farklı gübre dozlarının uygulanmasına olanak tanır. Bu, üretim maliyetlerini düşürür ve nitrat ve fosfatların neden olduğu çevresel kirliliği önler. Benzer şekilde, sensör destekli sulama sistemleri su kullanım verimliliğini artırarak kuraklık koşullarında üretimin sürdürülebilirliğine katkıda bulunur (Ali vd., 2025).

3.4. Karbon Ayak İzinin Azaltılması ve Çevresel Sürdürülebilirlik

Akıllı tarım teknolojileri yalnızca üretim verimliliğini artırmakla kalmayıp, tarımsal faaliyetlerden kaynaklanan sera gazı emisyonlarının azaltılmasına da katkıda bulunmaktadır. Gereksiz traktör geçişlerinin azaltılması, hassas ilaçlama sistemleri, enerji verimli sulama ekipmanları ve yenilenebilir enerji destekli otomasyon sistemleri karbon ayak izinin düşürülmesini sağlamaktadır. Bunun yanında drone destekli hedefe yönelik ilaçlama uygulamaları sayesinde pestisit tüketiminde önemli azalmalar sağlanabilmekte, toprak sıkışması önlenmekte ve doğal ekosistem üzerindeki baskı azaltılmaktadır. Bu uygulamalar, iklim dostu meyvecilik sistemlerinin geliştirilmesinde önemli araçlar olarak değerlendirilmektedir (Lobus ve ark., 2023; Awais ve ark., 2026)

4. Gelecek Perspektifleri

Tarım sektöründeki dijital dönüşüm, önümüzdeki yıllarda meyve üretim sistemlerini temelden değiştirecektir. Özellikle, Tarım 4.0 yaklaşımı çerçevesinde geliştirilen akıllı teknolojilerin, iklim değişikliğine uyum sürecinde merkezi bir rol oynaması beklenmektedir (Taoufik ve ark., 2024)

Gelecekte, meyve bahçelerinde dijital ikiz teknolojilerinin yaygın olarak benimsenmesi öngörülmektedir. Bu sistemler, meyve bahçesinin sanal bir modelini oluşturarak, gerçek üretime başlamadan önce iklim senaryolarının, sulama stratejilerinin ve gübreleme uygulamalarının simülasyonuna olanak sağlayacaktır. Bu, farklı yönetim seçeneklerinin verim, kalite ve su tüketimi üzerindeki etkisinin önceden değerlendirilmesini sağlayacaktır.

Robotik sistemlerin geliştirilmesiyle, budama, meyve seyreltme, hasat ve kalite sınıflandırma süreçlerinin büyük ölçüde otomatikleştirilmesi beklenmektedir. Yapay zeka destekli görüntü işleme sistemleri, olgunluk seviyesini belirleyerek seçici hasadı mümkün kılacaktır. Aynı zamanda, otonom kara araçları ve drone teknolojilerinin entegrasyonu, meyve bahçelerinin sürekli izlenmesine olanak sağlayacaktır.

Biyoteknolojideki gelişmeler de iklim değişikliğine uyum sürecinde önemli bir rol oynayacaktır. Genom düzenleme teknikleri ve moleküler ıslah çalışmaları, ısıya, kuraklığa ve tuzluluk stresine dayanıklı yeni meyve çeşitlerinin geliştirilmesini mümkün kılacaktır. Bu çeşitlerin akıllı tarım teknolojileriyle birlikte kullanılması, gelecekte sürdürülebilir meyve yetiştirme sistemlerinin temelini oluşturacaktır.

Geri bildirim gönderBununla birlikte dijital teknolojilerin yaygınlaştırılmasında bazı sınırlılıklar bulunmaktadır. Yüksek yatırım maliyetleri, dijital altyapı eksiklikleri, veri güvenliği sorunları ve üreticilerin teknik bilgi düzeylerinin yetersiz olması bu teknolojilerin benimsenmesini sınırlandırmaktadır. Bu nedenle kamu kurumları, üniversiteler, araştırma merkezleri ve özel sektör arasında güçlü iş birliklerinin geliştirilmesi, üreticilere yönelik eğitim programlarının yaygınlaştırılması ve dijital tarım yatırımlarının teşvik edilmesi büyük önem taşımaktadır.

Sonuç

İklim değişikliği, meyvecilik sektörünü üretimden pazarlamaya kadar tüm aşamalarda etkileyen küresel bir tehdit hâline gelmiştir. Artan sıcaklıklar, düzensiz yağış rejimleri, kuraklık, geç ilkbahar donları ve zararlı-hastalık baskısındaki artış, geleneksel üretim sistemlerinin sürdürülebilirliğini zorlaştırmaktadır. Bu nedenle iklim değişikliğine uyum sağlayabilen üretim modellerinin geliştirilmesi, meyvecilik sektörünün geleceği açısından stratejik önem taşımaktadır.

Akıllı tarım teknolojileri; gerçek zamanlı veri toplama, yapay zekâ destekli analiz, uzaktan algılama, otomasyon ve karar destek sistemleri sayesinde üretim süreçlerinin daha verimli ve sürdürülebilir şekilde yönetilmesini mümkün kılmaktadır. Bu teknolojiler su ve gübre kullanım etkinliğini artırmakta, pestisit kullanımını azaltmakta, çevresel etkileri sınırlandırmakta ve üretim risklerini minimize etmektedir. Aynı zamanda karbon ayak izinin azaltılmasına ve doğal kaynakların korunmasına katkı sağlayarak iklim dostu tarım uygulamalarını desteklemektedir.

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TIBBİ SÜLÜK SALGISINDA BULUNAN BİYOAKTİF BİLEŞİKLERİN TERAPÖTİK POTANSİYELİ

THE RAPEUTIC POTENTIAL OF BIOACTIVE COMPOUNDS FOUND IN MEDICINAL LEECH SALIVA

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ÖZET
Tıbbi sülükler (Hirudo şifalıis ve Hirudo verbana), yüzyıllardır geleneksel ve modern tıpta kullanılan önemli biyolojik organizmalardır. Tedaviye etki eden etkiler büyük ölçüde beslenme sırasında salgıladıkları biyolojik olarak aktif moleküllerden oluşur. Günümüzde proteomik ve transkriptomik çalışmalar, sülük salgısında 100'den fazla protein, peptit ve enzim bulunduğu ortaya çıktı. Bu heykel; antikoagülan, antiinflamatuvar, antimikrobiyal, analjezik, trombolitik, antioksidan ve rejeneratif özellikleri göstermektedir. Özellikle hirudin, kalin, destabilaz, bdellin, eglin, antistasin ve hyaluronidaz gibi moleküller, kalıcı patojenler, kronik yaralar, osteoartrit, rekonstrüktif cerrahi ve doku rejenerasyonu gibi birçok alanda terapötik potansiyel olabilir. Bu derlemede tıbbi sülük salgısında bulunan temel biyoaktif resimler, etki birimi ve güncel klinik kullanım alanları değerlendirilmiştir.
Anahtar Kelimeler: Tıbbi sülük, hirudin, biyoaktif bileşikler, hirudoterapi, antikoagülan, terapötik potansiyel.

ABSTRACT
Medicinal leeches (Hirudo verbana and Hirudo medicinalis) have been widely used in both traditional and modern medicine for centuries. Their therapeutic value is attributed not only to the bioactive compounds they secrete during feeding, but also to their unique feeding biology. This review comprehensively evaluates the feeding behavior, blood-sucking mechanisms, digestive physiology, and environmental factors influencing the feeding of medicinal leeches, based on current scientific literature. Medicinal leeches are obligate hematophagous organisms that feed exclusively on the blood of vertebrate hosts. During feeding, they secrete a variety of biologically active compounds, including hirudin, kalin, destabilase, hyaluronidase, and vasodilators, which inhibit blood clotting and facilitate prolonged blood intake. After a single feeding event, leeches can store blood equivalent to several times their body weight. Their low metabolic rate, combined with the presence of symbiotic bacteria in their digestive system, allows them to survive for several months or even more than a year without the need for supplemental feeding. Feeding performance is largely influenced by environmental factors such as temperature, water quality, dissolved oxygen concentration, pH, light conditions, host selection, and culture practices. Furthermore, differences between natural and artificial feeding systems used in laboratory and commercial production significantly impact breeding efficiency and animal health. A comprehensive understanding of the nutritional biology of medicinal leeches is essential for improving sustainable breeding practices, developing therapeutic applications, and supporting conservation strategies. This review summarizes current knowledge regarding the nutritional and feeding characteristics of medicinal leeches and provides a scientific foundation for future research in the fields of medicinal leech biology, aquaculture, and biomedical applications.
Keywords: Medicinal leech, *Hirudo verbana*, hematophagy, feeding biology, hirudin, aquaculture.

TIBBİ SÜLÜKLERİN BESLENME ÖZELLİKLERİ: GENEL BİR DEĞERLENDİRME

NUTRITIONAL CHARACTERISTICS OF MEDICINAL LEECHES: A GENERAL REVIEW

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ÖZET

Tıbbi sülükler (Hirudo verbana ve Hirudo medicinalis), yüzyıllardır geleneksel ve modern tıpta kullanılan önemli biyolojik organizmalardır. Terapötik süreçlerdeki başarıları, sadece salgıladıkları biyoaktif bileşiklerden değil, aynı zamanda benzersiz beslenme biyolojilerinden de kaynaklanmaktadır. Bu derleme, mevcut literatür ışığında tıbbi sülüklerin beslenme davranışını, kan emme mekanizmalarını, sindirim fizyolojisini ve beslenmeyi etkileyen çevresel faktörleri değerlendirmektedir. Tıbbi sülükler zorunlu hematofag organizmalardır ve sadece omurgalı hayvanların kanıyla beslenirler. Beslenme sırasında salgıladıkları hirudin, kalin, destabilaz, hiyalüronidaz ve çeşitli vazodilatör bileşikler sayesinde kan pıhtılaşmasını önleyebilir ve uzun süreli ve etkili kan emme gerçekleştirebilirler. Tek bir beslenmeden sonra vücut ağırlıklarının birkaç katı kadar kan depolayabilme yetenekleri, düşük metabolizma hızları ve sindirim sistemlerindeki simbiyotik bakteriler, tekrar beslenmeye ihtiyaç duymadan aylarca hatta bir yıldan fazla hayatta kalmalarını sağlar. Beslenme verimliliği, sıcaklık, su kalitesi, çözünmüş oksijen seviyeleri, pH, ışık, konak seçimi ve yetiştirme koşulları gibi birçok çevresel faktörden etkilenir. Ayrıca, laboratuvar ve ticari üretim koşullarında uygulanan yapay besleme yöntemleri ile doğal besleme arasındaki farklılıklar da üretim verimliliği açısından önemlidir. Sonuç olarak, tıbbi sülüklerin beslenme biyolojisinin ayrıntılı bir şekilde anlaşılması, sürdürülebilir su ürünleri yetiştiriciliği uygulamalarının geliştirilmesi, tıbbi kullanımın etkinliğinin artırılması ve türün korunmasına yönelik stratejilerin oluşturulması için büyük önem taşımaktadır. Bu derleme, tıbbi sülüklerin beslenme özelliklerine ilişkin güncel bilgileri bütüncül bir yaklaşımla sunarak gelecekteki araştırmalar için güncel bir kaynak sağlamayı amaçlamaktadır.

Anahtar Kelimeler*: Tıbbi sülük, Hirudo* verbana, hematofaji, beslenme biyolojisi, hirudin, yetiştiricilik.

ABSTRACT

Medicinal leeches (Hirudo verbana and Hirudo medicinalis) have been widely used in both traditional and modern medicine for centuries. Their therapeutic value is attributed not only to the bioactive compounds they secrete during feeding, but also to their unique feeding biology. This review comprehensively evaluates the feeding behavior, blood-sucking mechanisms, digestive physiology, and environmental factors influencing the feeding of medicinal leeches, based on current scientific literature. Medicinal leeches are obligate hematophagous organisms that feed exclusively on the blood of vertebrate hosts. During feeding, they secrete a variety of biologically active compounds, including hirudin, kalin, destabilase, hyaluronidase, and vasodilators, which inhibit blood clotting and facilitate prolonged blood intake. After a single feeding event, leeches can store blood equivalent to several times their body weight. Their low metabolic rate, combined with the presence of symbiotic bacteria in their digestive system, allows them to survive for several months or even more than a year without the need for supplemental feeding. Feeding performance is largely influenced by environmental factors such as temperature, water quality, dissolved oxygen concentration, pH, light conditions, host selection, and culture practices. Furthermore, differences between natural and artificial feeding systems used in laboratory and commercial production significantly impact breeding efficiency and animal health. A comprehensive understanding of the nutritional biology of medicinal leeches is essential for improving sustainable breeding practices, developing therapeutic applications, and supporting conservation strategies. This review summarizes current knowledge regarding the nutritional and feeding characteristics of medicinal leeches and provides a scientific foundation for future research in the fields of medicinal leech biology, aquaculture, and biomedical applications.

Keywords: Medicinal leech, *Hirudo verbana*, hematophagy, feeding biology, hirudin, aquaculture.

THE IKSAD INSTITUTE FOR ECONOMIC DEVELOPMENT AND SOCIAL RESEARCH OF TÜRKIYE

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Abstract: Sand flies (*Diptera: Psychodidae*) are the primary vectors of leishmaniasis, a disease whose current resurgence in the Fez region poses significant public health concerns. Conducted from May 2017 to April 2018 using sticky traps, this study aimed to characterize the seasonal dynamics and diversity of the local sand fly fauna. A total of 816 specimens were captured, revealing a clear male predominance (sex ratio = 20.46). The population was divided between the genera *Sergentomyia* (53.18%) and *Phlebotomus* (46.82%). Within the latter, *Phlebotomus sergenti* emerged as the dominant species (26.96%), followed by *Ph. perniciosus* (10.79%) and *Ph. papatasi* (9.07%), while *Sergentomyia minuta* predominated (44.24%) within its genus. Phenological analysis demonstrates that vector activity increases significantly starting in May. In conclusion, the marked presence of *Ph. sergenti* confirms an active risk of cutaneous leishmaniasis transmission within the city of Fez itself. These findings are essential for optimizing the timing of local vector control interventions.
Keywords: Sandfly, Biodiversity, Inventory, Cutaneous leishmaniasis, Fez, Central Morocco

HEAVY METAL TOXICITY AND SEDIMENT QUALITY ASSESSMENT IN LAKE DAYET ER-ROUMI (MOROCCO): INTEGRATED ENVIRONMENTAL INDICES AND MULTIVARIATE STATISTICS

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ABSTRACT
For many years, metallic contamination of surface sediments has attracted researchers attention from very different horizons. The Lake Dayet Er-Roumi classified as a Site of Biological and Ecological Interest is under the pressure of various pollution forms. The present study aimed to evaluate the metal contamination through spatio-temporal monitoring of several metallic trace elements:Al, pb, Mn, Ba, Zn, Fe, Cu, Co, Cr, Cd and Ni during 2018/2019 in four seasons. Three different sampling points were selected along the study area. The different contamination indices calculated show a very important enrichment; indeed, the contamination factor shows a very strong contamination for the Zn, Pb, and Cu, with a moderate contamination for the Mn and Cr. The results of the degree of contamination reveal a polymetallic contamination dominated by three elements, which are Zn, Pb, and Cu. Analysis of these indices allowed us to establish the classification order of the different stations in terms of contamination, which is as follows: S1>S3>S2. The calculation of the contamination indices confirms real polymetallic contamination, with worrying situations for several stations and several metallic elements. The hierarchical cluster analysis reveals common sources of these studied metals. The results obtained reflect extremely severe contamination by these elements and show strong pollution caused by local populations.
Keywords: Dayet Er-Roumi, Morocco, sediment, pollution, contamination factor, degree of contamination

INTEGRATED IN SILICO AND PRECLINICAL EVALUATION OF MORINDA CITRIFOLIA FRUIT EXTRACT FOR ANXIOLYTIC ACTIVITY: A NETWORK PHARMACOLOGY AND ELEVATED PLUS MAZE STUDY

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ABSTRACT

Introduction

Anxiety is a prevalent neuropsychiatric disorder characterised by excessive fear, apprehension, and emotional disturbances. *Morinda citrifolia* L. (noni) fruit contains bioactive phytoconstituents with potential neuroprotective and anxiolytic properties, but its molecular mechanisms remain insufficiently explored.

Purpose

The present study aimed to investigate the anxiolytic potential of *Morinda citrifolia* fruit extract (MCE) using an integrated *In-Silico* approach and preclinical evaluation in the Elevated Plus Maze (EPM) model.

Materials and Methods

Phytoconstituents of MCE were identified using phytochemical databases and evaluated for drug-likeness, pharmacokinetic properties, and ADMET profiles. Network pharmacology was employed to identify potential anxiety-related targets and signalling pathways, followed by molecular docking to investigate interactions between selected phytoconstituents and key target proteins. The anxiolytic activity of MCE was evaluated using the EPM apparatus by assessing open-arm entries and time spent in open arms and comparing the effects with the standard anxiolytic diazepam.

Results

The *In-Silico* analysis identified multiple anxiety-associated targets and signalling pathways. Selected phytoconstituents exhibited favourable binding interactions with relevant target proteins, supporting their potential pharmacological activity. In the EPM test, MCE-treated animals showed increased open-arm entries and time spent in open arms compared with the control group, indicating an anxiolytic-like effect.

Conclusion

The integrated findings suggest that MCE possesses promising anxiolytic potential, possibly through multi-target modulation of anxiety-associated pathways. Further mechanistic studies are warranted.

Keywords:*Morinda citrifolia*; Anxiety; Anxiolytic; Elevated Plus Maze; Network pharmacology; Molecular docking; ADMET.

A MATHEMATICAL ANALYSIS OF DYNAMIC SIR EPIDEMIOLOGICAL MODEL

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Abstract
This paper investigates a prior mathematical structure that depicts the dynamics of the Susceptible, Infectious, and Recovered (*SIR*) epidemic model**.** The relevant three compartments that comprise the framework, namely Susceptible, Infective, and Recovered (*SIR*), are analytically resolved via the Laplace Adomian Decomposition method (LADM). An approximate analytical outcome for each of the three compartments is listed. A wide range of model parameter types are visually shown to demonstrate their impacts. Then compare our approximate analytical outcomes with the numerical simulation. A reasonable agreement between the numerical simulation (MATLAB) and the approximate analytical results is achieved.
Keywords: *SIR* model, Epidemic model, Non-linear initial value problem, Laplace Adomian Decomposition Method (LADM), Numerical simulation

Mathematical Subject classification: 34A05, 34A12, 34E05, 34E10.

THE HUMAN GUT MICROBIOME AS A RESERVOIR OF ANTIMICROBIAL RESISTANCE GENES: MECHANISMS OF RESISTANCE DEVELOPMENT AND DISSEMINATION

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ABSTRACT
The human gut microbiome plays an essential role in maintaining host health. However, it is increasingly recognized as an important reservoir of antimicrobial resistance genes (ARGs), as it provides a complex environment in which antibiotic exposure, microbial interactions, horizontal gene transfer, and changes in community structure influence the emergence and persistence of antimicrobial resistance. Consequently, the gut microbiome significantly contributes to the growing global gene pool of antimicrobial resistance (AMR), and the attendant public health threats. This review examines how the gut microbiota contributes to the development, maintenance, and dissemination of ARGs, with particular attention to the gut resistome and the factors that shape its composition. Recent evidence shows that even short courses of antibiotic administration can place strong selective pressure on commensal gut bacteria, leading to resistant populations that may persist after treatment. Additionally, the close coexistence of diverse bacterial species and mobile genetic elements within the gut may further facilitate the acquisition and transfer of ARGs. Antibiotic-induced disruption of the microbiome can also create ecological opportunities for resistant organisms to survive and expand. Understanding these processes is important because resistance determinants carried by gut bacteria may contribute to the persistence, colonization, and transmission of resistant organisms. Future efforts to control AMR should therefore combine antimicrobial stewardship with microbiome surveillance, metagenomic approaches, and microbiome-based interventions. Recognizing the gut microbiome as an active ecosystem in the development and spread of AMR could strengthen efforts to preserve antimicrobial effectiveness and protect human health.
Keywords: Antibiotic resistance, antimicrobial resistance, gut microbiome, horizontal gene transfer, resistome.

AGREEMENT BETWEEN FOUR VO_2PEAK ESTIMATION EQUATIONS AND HEALTH-RELATED FITNESS CLASSIFICATION IN ADOLESCENTS: LMS REFERENCE CURVES FROM KENITRA, MOROCCO

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ABSTRACT
To assess the agreement among four equations for estimating peak oxygen uptake (VO_2peak) from the 20-m shuttle-run test, to determine their impact on individual health-related fitness classification, and to develop smoothed reference percentiles for adolescents from Kénitra, Morocco.
This cross-sectional methodological validation study included 1185 adolescents aged 12–20 years (593 boys and 592 girls; 598 rural and 587 urban) from Kénitra Province, Morocco. Four VO_2peak estimates derived from the 20-m shuttle-run test were compared using Bland–Altman analysis. Agreement in health-related fitness classification was assessed using Cohen's kappa, sensitivity, and specificity, with 95% confidence intervals estimated by bootstrap resampling (2,000 replications). Multivariable analysis was used to examine the independent associations of sex, age, maturation, body mass index, and residential setting with VO_2peak. Smoothed age-specific reference percentiles for maximal aerobic speed and VO_2peak were constructed using the LMS method.
The absolute VO_2 estimate showed the smallest overall mean bias relative to the reference estimate (+0.23 $mL \cdot kg^{-1} \cdot min^{-1}$), although the limits of agreement remained wide (−11.1 to +11.5 $mL \cdot kg^{-1} \cdot min^{-1}$), indicating limited individual-level agreement. The Léger equation showed substantial maturation-related bias, overestimating VO_2peak in post-pubertal adolescents (+6.4 $mL \cdot kg^{-1} \cdot min^{-1}$) and underestimating it in pre-pubertal adolescents (−2.2 $mL \cdot kg^{-1} \cdot min^{-1}$; proportional bias, $p < 0.001$). Classification agreement was low across methods ($\kappa = 0.24–0.25$). The Léger equation classified 38.4% of participants as being at risk compared with 16.0% according to the reference estimate, with a sensitivity of 71.1% and specificity of 67.8%. Other estimates showed lower sensitivity (approximately 32–35%). Sex, residential setting, maturation, and age were independently associated with VO_2peak, whereas BMI showed no independent effect. Smoothed LMS reference curves were generated for maximal aerobic speed and VO_2peak.
The four VO_2peak estimation equations should not be considered interchangeable for individual-level health-related fitness classification. Differences between equations may substantially alter the proportion of adolescents classified as being at risk, despite relatively small mean biases. The LMS reference curves provide locally relevant reference values for adolescents in the Kénitra region and represent a basis for future multicentre studies aimed at developing nationally representative Moroccan reference standards.
Keywords: VO_2peak; 20-m shuttle-run test; LMS method; criterion validity; school-based screening.

ANTI-DIARRHOEAL AND TOXICOLOGICAL PROPERTIES OF

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Abstract
The folkloric claim of *Cassia singueana* root for treatment of diarrhoeal was investigated through castor oil induced diarrhoea, gastrointestinal transit and castor oil induced enteropooling models in rats. The phytochemical, toxicological and antidiarrhoeal properties of its methanolic root extract were studied. The crude methanolic root extract was partitioned using hexane, ethylacetate and butanol (saturated with water). The hexane, ethylacetate and saturated butanol fractions were also screened for antidiarrhoeal properties. The protein precipitation rate of crude methanolic extract, ethylacetate and saturated butanol fractions were evaluated. The most potent fractions, ethylacetate and saturated butanol were screened for antibacterial activities against *Escherichia coli*, *Pseudomonas aeruginosa* and *Staphylococcus aureus.* The median lethal dose (LD_{50}) of the crude extract was greater than 5000mg/kg and no mortality was recorded. The phytochemical analysis revealed presence of alkaloids, flavonoids, glycosides, saponins, tannins, steroids, balsams, tarpenes and saponin glycosides. The methanol extract, ethylacetate and saturated butanol fractions exhibited significant ($p<0.05$) inhibition of castor oil induced diarrhoea in rat compared to loperamide, produced significant decrease in intestinal transit and significantly inhibited castor oil induced enteropooling in rats. The ethylacetate and saturated butanol fractions exhibited antibacterial activity against *Escherichia coli*, *Pseudomonas aeruginosa* and *Staphylococcus aureus.* Protein precipitation rate on crude methanolic extract, ethylacetate and saturated butanol fractions were found to increase as the concentration of tannins increases. Oral administration of methanolic root extract daily for 28 days reveals non significant ($p>0.05$) difference on most of the body weight of rats, liver function, renal and hematological indices. This results show that the root extracts of *Cassia singueana* contains phytochemicals that may be responsible for its antidiarrhoeal, antibacterial activities and may have relatively low toxicity profile.
Keywords: *Cassia singueana*, Diarrhoeal, toxicological studies and phytochemical.

LIQUID BIOPSY IN BREAST CANCER: EMERGING BIOMARKERS FOR EARLY DETECTION AND TREATMENT MONITORING

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Abstract
Breast cancer remains one of the most frequently diagnosed malignancies worldwide, highlighting the need for innovative and minimally invasive approaches for early detection, disease monitoring, and treatment optimization. Liquid biopsy has emerged as a promising strategy based on the analysis of tumor-derived components circulating in biological fluids, particularly blood. Unlike conventional tissue biopsy, liquid biopsy offers the possibility of repeated sampling, providing dynamic information about tumor evolution and treatment response.
Several circulating biomarkers have attracted increasing attention in breast cancer research, including circulating tumor DNA (ctDNA), circulating tumor cells (CTCs), cell-free DNA, circulating microRNAs, and extracellular vesicles. These biomarkers may provide valuable information regarding tumor heterogeneity, molecular alterations, minimal residual disease, treatment resistance, and disease progression. In particular, ctDNA analysis has demonstrated potential for detecting molecular alterations and identifying emerging resistance mechanisms before clinical progression becomes evident. Similarly, CTCs may contribute to prognostic assessment and monitoring of metastatic disease.
Despite these promising applications, several challenges remain, including the low abundance of tumor-derived material, methodological heterogeneity, analytical sensitivity, and the lack of standardized protocols for routine clinical implementation. Integrating multiple circulating biomarkers with molecular and clinical data may improve the reliability and clinical utility of liquid biopsy.
Overall, liquid biopsy represents a rapidly developing approach with considerable potential to complement conventional diagnostic strategies in breast cancer. Further prospective studies and standardized analytical frameworks are required to establish its role in personalized cancer management and routine clinical practice.
Keywords: Breast cancer; Liquid biopsy; Circulating tumor DNA; Circulating tumor cells.

CURRICULUM REFORM FOR 21ST CENTURY SKILLS AND EMPLOYABILITY IN EDUCATIONAL ADMINISTRATION

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ABSTRACT
The rapid transformation of the global economy driven by technological advancement, globalization, digitalization and changing labour market demands, has necessitated a reconsideration of educational curricular which primarily emphasized theoretical knowledge acquisition, are increasingly inadequate for preparing graduates for contemporary workplace realities. Thus this opinion paper argues that curriculum reform is important for integrating 21st century skills and enhancing employability outcome particularly within educational administration programme. This paper advocates for competency-based curricula that emphasize critical thinking, creativity, communication, collaboration, digital literacy, leadership, entrepreneurship and problem solving skills. It further highlights the role of educational administrators in driving curriculum innovation and recommends strategies for effective implementations.
Keywords: Curriculum reform, 21st century skills, employability, educational administration

NURSE'S LEGAL KNOWLEDGE AND COMPLIANCE WITH INFORMED CONSENT STANDARDS: A COMPARATIVE STUDY OF FEDERAL UNIVERSITY TEACHING HOSPITAL, LAFIA AND FEDERAL MEDICAL CENTRE, KEFFI, NASARAWA STATE, NIGERIA

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ABSTRACT

Background

Informed consent is a fundamental legal and ethical requirement that safeguards patients' autonomy and promotes quality healthcare delivery. Nurses play a pivotal role in ensuring that informed consent is properly obtained, understood, documented, and upheld throughout patient care. However, deficiencies in legal knowledge and institutional barriers may compromise compliance with informed consent standards, thereby increasing the risk of ethical violations and medico-legal litigation. This study assessed nurses' legal knowledge and compliance with informed consent standards in two tertiary healthcare institutions in Nasarawa State, Nigeria.

Objective

To assess nurses' legal knowledge and compliance with informed consent standards and compare compliance practices between Federal University Teaching Hospital (FUTH), Lafia, and Federal Medical Centre (FMC), Keffi.

Methods: A comparative descriptive cross-sectional study was conducted among 230 registered nurses selected through a multistage sampling technique from FUTH Lafia (n = 124) and FMC Keffi (n = 106). Data were collected using a validated structured self-administered questionnaire with a Cronbach's alpha coefficient of ≥0.70. Data were analysed using SPSS version 25. Descriptive statistics summarized respondents' characteristics and study variables, while Spearman's rank correlation and the Mann-Whitney U test were used to test the hypotheses at a 5% level of significance.

Results

The response rate was 100%. Nurses demonstrated a high level of legal knowledge on informed consent (mean scores = 2.79–2.99) and a high level of compliance with informed consent standards (mean scores = 2.85–2.92). The most influential factors affecting compliance were poor communication skills (Mean = 2.93 ± 0.31), continuous professional education (Mean = 2.93 ± 0.32), inadequate training (Mean = 2.79 ± 0.47), and heavy workload (Mean = 2.70 ± 0.59). Spearman's correlation revealed no statistically significant relationship between legal knowledge and compliance ($r_s = 0.055$, $p = 0.405$). Furthermore, compliance did not differ significantly between FUTH Lafia and FMC Keffi (Mann-Whitney U = 5943.50, Z = -1.511, p = 0.131).

Conclusion

Although nurses exhibited high legal knowledge and compliance with informed consent standards, legal knowledge alone was insufficient to predict compliance. Institutional and organizational factors appeared to exert greater influence on compliance behaviours. Strengthening continuous legal education, improving communication competencies, conducting regular clinical audits, and addressing staffing shortages are recommended to enhance informed consent practices, protect patients' rights, and minimize medico-legal risks in tertiary healthcare institutions.

Keywords: Legal knowledge, informed consent, compliance, nurses, nursing jurisprudence, patient rights, tertiary hospitals, Nigeria.

DISCIPLINE/ TOPIC: BIOLOGY

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ABSTRACT
The performance of *Clarias gariepinus* (Burchell, 1822) hatchlings fed varying levels of dietary beetroot powder was evaluated. Beetroot powder was included into Coppens fish feed (0.2 – 0.5mm) with 49% crude protein at; 0.0g (BR_1 as control), 0.25g (BR_2), 0.5g (BR_3), 0.75g (BR_4) and 1.0g/100g feed (BR_5). Feed was fed to *C. gariepinus* hatchlings (n = 1,500, 0.25±0.0g) in triplicates for a period of 28 days in 15 plastic hatchery tanks (n = 100). Hatchlings were fed feed at a fixed feeding rate of 10% body weight 6 times daily between the hours of 07:00 and 23:00 at regular interval. Data obtained was statistically analysed using One - way ANOVA at P = 0.05. Survival rate was statistically significantly ($P < 0.05$) higher in BR_3 (95.20±1.68 %), while it was least in BR_1 (87.60±1.08 %). Feed conversion ratio was not statistically significant ($P > 0.05$) least (best) in BR_3 (0.430±0.05), while it was highest (poor) in BR_1 (0.451±0.17). Mean weight gain (1.90±0.16 g/fish), daily weight gain (0.077±0.17 g/day) and specific growth rate (3.46±0.24 %/day) were higher, but not statistically significantly ($P > 0.05$) in hatchlings fed feed BR_3, while feed BR_1 had the least mean weight gain (1.56±0.04 g/fish), daily weight gain (0.055±0.04 g/day) and specific growth rate (3.01±0.10 %/day). The Inclusion of dietary beetroot powder into *C. gariepinus* hatchlings feed employed in this study significantly ($P<0.05$) increased the survival rate values.
Keywords: Coppens, Fish Feed, Growth, Inclusion, Survival Rate.

INTRODUCTION

The hatchlings stage is considered as the most critical periods in the life cycles of cultured fish species (Ali *et al.*, 2024). The success of fish hatchlings culturing depends mainly on the availability of suitable feed or food that are readily eaten with efficiency of digestion and provision of the needed nutrients for growth, good health and survival of the fish larvae (Mehrabi *et al.*, 2018). However, the culturing of fish at the hatchlings stage has been a great challenge for many fish breeders (Onyia *et al.*, 2016). Functioning and standard of the cultured species can really be promoted by understanding the special nutritional requirements of fish hatchlings. The selection of minute feed particles can result to nutrient leaching due to very high ratio surface to area volume (Ali and Tahir, 2026). Live prey organisms, primarily zooplanktons, are mostly used as the starter food for the hatchlings of many cultured fish species that are not suitable to be reared on formulated feed (Ali *et al.*, 2024). The high cost of feed is a constraint to fish farmers particularly in the tropical countries such as Nigeria (Ishaku *et al.*, 2025). This has necessitated the need for alternative feeds like special fish feed incorporated with growth promoters as natural feed additives such as beetroot powder which positively affect the body weight gain without any negative effect on public health and consumer (Ali *et. al.*, 2025).

Plants such as beetroot and maca are natural source of safer and cheaper bio - chemicals and the beneficial effects of bioactive plant substances in animal nutrition may include the stimulation of appetite and feed intake, the improvement of endogenous digestive enzyme secretion, activation of immune responses and antibacterial, antiviral and antioxidant actions (Tahir *et al.*, 2025; Ali *et. al.*, 2025). This study evaluates the performance of *Clarias gariepinus* (Burchell, 1822) hatchlings fed varying levels of dietary beetroot powder.

MATERIALS AND METHODS

Study Area

The study was carried out at the Lay – Joy fish farm Billiri. Billiri local government area (LGA), Gombe State. Billiri LGA lies within latitude 9°50' and 11°09''N and longitude 9.833°and 11.150°E. It covers an area of 737km² and is 50 km away from Gombe the capital city. The hatchlings for the experiment were bred at the hatchery room of the farm. The hatchlings were 4 days old at the commencement of the feeding trial.

Experimental Feed

Coppens fish feed (0.2 – 0.5mm) was used as the basal feed for this study and was obtained from feed suppliers at Gombe while the beetroot powder was purchased from Bon - Amour Pharmacy Limited Lagos, Nigeria, imported from Piping Rock Health Products, Ronkonkoma, New - York, USA. Experimental feed was prepared by the inclusion dietary beetroot powder at four graded levels; 0.25g, 0.5g, 0.75g and 1.0g/100g feed into Coppens fish feed (0.2 – 0.5mm), while feed without dietary mandrake root powder i.e. 0.0g/100g feed served as the control feed and were coded as BR_1 (control), BR_2, BR_3, BR_4 and BR_5 respectively. The dietary beet root powder was included at the measured quantity for each feed and was diluted into 5 ml of warm water (35^0C) to form a solution. The solution was sprayed onto the Coppens fish feed (0.2 – 0.5mm), fish oil was added to the experimental feed with beetroot powder to reserve the beetroot powder. The Coppens fish feed (0.2 – 0.5mm) with dietary beet root powder was prepared in 100g each time. The proximate composition of the Coppens fish feeds (0.2 – 0.5mm) fed to the *C. gariepinus* hatchlings is presented in Table 1. The feed contained 49% crude protein, 12% crude lipid, 6.0% crude fibre, 8.0% ash, 1.5% calcium, 8.0% moisture and 1.5% phosphorus.

Table 1: Proximate Composition of Coppens C. gariepinus Hatchlings Feed (0.2 – 0.5 mm) used for the Study

Nutrients	Percentage (%)
Crude protein	49
Crude lipid	12
Crude fibre	6.0
Ash	8.0
Calcium	1.5
Moisture	8.0
Phosphorus	1.5

Source: Ali and Tahir (2026).

Experimental Design

Each of the treatment feed was fed to *C. gariepinus* hatchlings (n = 1,500; 0.25±0.0g) in triplicate making a total of 15 plastic hatchery tanks (semi flow - through system) i.e. (n = 100 per tank). Water quality parameters such as; pH, dissolved oxygen (DO), temperature and ammonia were monitored weekly. Hatchlings were fed 6 times daily between the hours of 07:00 and 23:00 at regular interval for a period of 28 days at a fixed feeding rate of 10% body weight as recommended by Ukwe *et al.* (2018). The initial body weight of each set of hatchlings was measured using a digital weighing balance before stocking and subsequently bulk weighing of hatchlings in each tank was done after every 7 days, the growth performance parameters were computed and analyzed according to the following equations as described by Stickey *et al.* (2006) as follows;

$$Mean\ weight\ gain, MWG = final\ weight\ (g) - initial\ weight\ (g)$$

$$Daily\ weight\ gain, DWG = \{final\ weight\ (g) - initial\ weight\ (g)\}/experimental\ days$$
$$Specific\ Growth\ Rate, SGR = \{(log\ final\ weight\ (g) - log\ initial\ weight\ (g)\}/culture\ period\} \times 100$$
$$Feed\ Conversion\ Ratio, FCR\ (g/g) = feed\ intake\ (g)/weight\ gain\ (g)$$
$$Survival\ rate = \{(final\ no.of fish - initial\ no.of fish)/initial\ no.of\ fish\} \times 100$$

Statistical Analysis

Data obtained were statistically analysed using one – way analysis of variance (ANOVA) at P = 0.05, where significant differences were detected, mean values were separated using least significant difference (LSD).

RESULTS

Results of the performance of *C. gariepinus* hatchlings fed varying levels of dietary beetroot powder is shown in Table 2. Survival rate values recorded significant increases (P<0.05) with inclusion of dietary beetroot powder, while feed conversion ratio values decreased (P>0.05). The mean weight gain, daily growth rate and specific growth rate values were not significantly influenced (P>0.05) with the inclusion of dietary beetroot powder.

Table 2: Performance of C. gariepinus Hatchlings Fed Varying Levels of Dietary Beetroot Powder

Parameters	BR_1	BR_2	BR_3	BR_4	BR_5
Initial mean weight (g/fry)	0.25±0.0[a]	0.25±0.0[a]	0.25±0.0[a]	0.25±0.0[a]	0.25±0.0[a]
Final mean weight (g/fry)	1.81±0.11[c]	1.88±0.17[c]	2.15±0.28[c]	2.10±0.19[c]	2.07±0.23[c]
Mean weight gain (g/fry)	1.56±0.04[b]	1.63±0.08[b]	1.90±0.16[b]	1.85±0.13[b]	1.82±0.09[b]
Daily growth rate (g/day)	0.055±0.04[a]	0.059±0.07[a]	0.077±0.17[a]	0.072±0.13[a]	0.070±0.10[a]
Specific growth rate (%/day)	3.01±0.10[e]	3.09±0.16[e]	3.46±0.24[e]	3.33±0.20[e]	3.28±0.19[e]
Feed conversion ratio (g/fry)	0.451±0.17[d]	0.443±0.14[d]	0.430±0.05[d]	0.435±0.07[d]	0.437±0.10[d]
Survival rate (%)	87.60±1.08[a]	90.50±1.12[b]	95.20±1.68[c]	91.00±1.22[b]	91.00±1.15[b]

Mean values in each row with similar superscripts are not significantly different (p>0.05).
Key: BR_1 – Beetroot powder (0.0g/100g), BR_2 – Beetroot powder (0.25g/100g), BR_3 – Beetroot powder (0.5g/100g), BR_4 – Beetroot powder (0.75g/100g) and BR_5 – Beetroot powder (1.0g/100g).

DISCUSSION

The significant increases in the survival rate values of *C. gariepinus* hatchlings fed feed with inclusion of dietary beetroot powder obtained from this study was in consistent with the findings of Jibrin and Ali (2024) who reported significant increases in the survival rate values of *C. gariepinus* hatchlings fed maca (*Lepidium meyenii* Walp.) root powder. The decreased in the feed conversion ratio values with inclusion of dietary beet root powder was agreement with the findings of Ali and Tahir (2026) who reported that the inclusion of dietary mandrake root powder into *C. gariepinus* feed lower the feed conversion ratio values. The mean weight gain, daily growth and specific growth rate values were not influenced by the inclusion of dietary beetroot powder which was in contrast with the findings of Ali *et al.* (2023) and Ali *et al.* (2024) which both reported that the inclusion of dietary betaine hydrochloride and dietary β – glucan levels into *C. gariepinus* fry feed significantly increased the mean weight gain, daily growth rate and specific growth rate values The dietary beetroot powder was well tolerated by the *C. gariepinus* hatchlings and does not have any negative effect on the water quality parameters during the study.

CONCLUSION

The inclusion of dietary beetroot powder at 0.25g, 0.5g, 0.75g and 1.0g/100g feed into *C. gariepinus* hatchlings feed employed in this study significantly (P<0.05) increased the survival rate values.

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AN AI-DRIVEN HYBRID SENTIMENT ANALYSIS FRAMEWORK FOR INTELLIGENT HEALTHCARE FEEDBACK CLASSIFICATION USING MACHINE LEARNING AND TRANSFORMER MODELS

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ABSTRACT

Introduction and Purpose: The rapid increase of virtual healthcare structures has generated huge volumes of patient evaluations and remarks containing valuable information approximately healthcare studies. however, manually analyzing such unstructured textual facts is time-ingesting and subjective. This examine proposes a artificial intelligence (AI)-pushed hybrid sentiment analysis framework for robotically classifying healthcare-related remarks into fantastic, neutral, and negative categories.

Materials and Methods: The proposed framework integrates time period Frequency–Inverse report Frequency (TF-IDF), contextual embeddings from transformer-based language fashions, and VADER sentiment scores to capture lexical, contextual, and sentiment-stage statistics. more than one device studying classifiers, inclusive of support Vector device, Random woodland, Gradient Boosting, and supplement Naive Bayes, are evaluated. a attention-based mechanism is included to pick out the maximum informative functions for sentiment category. widespread preprocessing, characteristic extraction, model training, and evaluation techniques are implemented.

Results: The hybrid framework demonstrates advanced sentiment class capability compared with individual traditional gadget learning and lexicon-based tactics. the combination of contextual transformer representations with statistical and sentiment capabilities gives extra robust identity of complex healthcare opinions and emotionally expressed comments.

Discussion and Conclusion: The findings indicate that AI-based totally sentiment analysis can help healthcare agencies in systematically knowledge affected person reports and figuring out regions requiring development. The proposed framework presents an scalable computational method for reworking unstructured healthcare comments into actionable insights.

Keywords: Artificial Intelligence, Sentiment Analysis, Healthcare, Machine Learning, Natural Language Processing, Transformers, Patient Feedback

AN ENHANCED HYBRID TRANSFORMER-BASED SENTIMENT ANALYSIS FRAMEWORK FOR MEDICAL AND HEALTH-RELATED ONLINE PATIENT FEEDBACK

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ABSTRACT

Introduction and Purpose

The speedy boom of on-line health platforms and social media has generated huge volumes of affected person feedback containing treasured data approximately healthcare studies, offerings, and satisfaction. This examine proposes an more desirable Hybrid Sentiment class framework for robotically reading clinical and health-associated textual feedback the usage of device learning, sentiment lexicons, contextual embeddings, and interest mechanisms.

Materials and Methods

The proposed framework integrates term Frequency–Inverse record Frequency (TF-IDF) functions, VADER sentiment scores, and Transformer-based totally contextual representations. more than one machine getting to know classifiers, such as complement Naïve Bayes, Random woodland, Gradient Boosting, and support Vector machine, are evaluated. a Multi-Head attention mechanism is included to identify and assign extra importance to informative textual functions. wellknown preprocessing and evaluation procedures are implemented to categorise comments into fine, impartial, and negative sentiment classes.

Results

Experimental assessment demonstrates that the proposed hybrid method presents extra regular and effective sentiment class than person traditional machine gaining knowledge of and lexicon-primarily based approaches. the mixing of contextual Transformer representations with conventional linguistic features improves the identity of complex sentiment styles in health-associated comments.

Discussion and Conclusion

The findings indicate that AI-pushed sentiment analysis can guide healthcare agencies in understanding affected person reviews, identifying carrier-related concerns, and enhancing statistics-pushed selection-making. The proposed framework provides a scalable computational technique for extracting actionable insights from large volumes of scientific and healthcare feedback.

Keywords: Artificial Intelligence, Sentiment Analysis, Healthcare Analytics, Patient Feedback, Natural Language Processing, Transformer, Machine Learning, Multi-Head Attention

DIGITAL APPLICATIONS FOR THE SIX-MINUTE WALK TEST IN NORMAL ADULTS: A PROTOCOL OF SYSTEMATIC REVIEW

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ABSTRACT

Background: The six-minute walk test (6MWT) is a widely used sub-maximal test of functional exercise capacity, traditionally performed under supervision on a standardized 30-metre corridor. Smartphone applications have been developed to allow digital, self-administered versions of the test. Most existing validation evidence comes from diagnosed clinical populations, and no systematic synthesis currently exists on the accuracy, reliability, and usability of these tools specifically in normal adults.

Objectives: To systematically identify, appraise, and synthesize evidence on the validity, reliability, and usability of digital applications and used to perform the 6MWT in normal adults.

Methods: This protocol follows the PRISMA-P 2015 guidelines and was prospectively registered with PROSPERO (Registration No. CRD420261473809).Eligible studies will include normal adults (≥18 years) in whom a 6MWT was performed using a digital application. PubMed/MEDLINE, Google Scholar, and the Cochrane Library will be searched. Two reviewers will independently screen records, extract data, and assess risk of bias using MARS(Mobile App Rating Scale).

Results: The review is expected to identify and classify various mobile applications used for conducting, monitoring, recording, or supporting the6MWT. Using the MARS, the study is expected to reveal differences in the overall quality, usability, functionality, engagement, aesthetics, and information quality of these applications.

Keywords: Normal adults, Mobile Applications, Six-Minute Walk Test, Six-Minute Walk Distance, 6MWT,6MWD.

EFFECTS OF AQUEOUS EXTRACT OF CINNAMOMUM VERUM ON GASTRIC ULCERS INDUCED BY LONG-TERM LOW-DOSE ASPIRIN IN MALE WISTAR RATS

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ABSTRACT
Low dose Aspirin, a widely used non-steroidal anti-inflammatory drug (NSAID), is known for its beneficial effects in cardiovascular disease prevention due to its antiplatelet properties. However, long-term use of aspirin is associated with adverse effects on the gastrointestinal (GI) mucosa, such as gastric ulceration and bleeding. Herbal remedies like cinnamon extract have been explored for their potential gastroprotective effects, aiming to mitigate aspirin-induced mucosal damage; this study investigates the protective effects of aqueous cinnamon bark extract against aspirin-induced ulcers in Wistar rats. forty rats, weighing 120-160g, were acclimatized to laboratory conditions with unrestricted access to standard rodent diets and drinking water, The experimental design included treatment groups receiving cinnamon extract at doses of 400mg/kg and 800mg/kg, + 75mg/kg Aspirin, administered orally. Control groups included normal controls given distilled water (10 mL/kg), an ulcerated control group receiving Aspirin (75mg/kg), and a positive control group given aspirin (75mg/kg) + cimetidine (50mg/kg). After 28 days, the rats were euthanized, and their stomachs, blood and gastric juice were examined. The ulcer score significantly increased in the aspirin-treated group (10.0 ± 0.0) compared to the distilled water group (3.5 ± 0.5), highlighting aspirin's ulcerogenic potential ($p = 0.013$). Co-administration of cinnamon extract significantly reduced the ulcer score, particularly at 400 mg/kg (0.0 ± 0.0), demonstrating its therapeutic potential ($p = 0.001$). In the current study however, no significant changes were observed in pepsin and mucos concentrations, Similarly, no significant differences in acid volume or pH levels were detected across treatment groups, On the oxidative stress biomarkers, catalase activity increased significantly in the ASP 75 mg/kg + CN 400 mg/kg group, compared to the aspirin-only group ($p = 0.028$), while MDA levels significantly decreased with higher doses of cinnamon ($p = 0.014$). Histopathological examination revealed intact gastric mucosa and undamaged gastric pits in groups treated with cinnamon extract; in conclusion this study provides compelling evidence of the significant protective effect of aqueous cinnamon bark extract against aspirin-induced gastric ulcers in Wistar rats, primarily through enhanced antioxidant activity and preserved gastric mucosal integrity. These findings suggest that cinnamon extract could be a promising therapeutic agent for preventing and treating gastric ulcers.

Keywords: Aspirin, Non-Steroidal Anti-Inflammatory Drug, Cinnamon, Gastro-Intestinal Tract, Low Dose Aspirin

1.0 INTRODUCTION
Low dose Aspirin define as (LDA, 75–350 mg/day), the role of aspirin in preventing cardiovascular events in people with a history of cardiovascular disease (CVD) has been well established (Bibbins-Domingos *et al.*, 2016) prescribe for prevention of heart attacks - strokes - cardiovascular problems in patients who suffer from stable or unstable angina contains, acetylsalicylic acid can cause gastric lesion in low doses, it belong to a group of medicines called anti-platelet agents (McNeil *et al*., 2018).

Aspirin is synthetic NSAIDs that are known to induce severe gastric mucosal lesions it irreversibly inhibits cyclo-oxygenase 1 (COX-1) which leads to inhibition of prostaglandins synthesis, which is important mediators of the inflammatory responses (Bartolucci et *al.*, 2011) Other factors responsible for gastric ulcers include steroidal drugs (prednisolone), tobacco smoking, psychological stress, alternative lifestyle and alcohol abuse. (Hayyan *et al.*, 2016). Gastric ulcer disease refers to the defect in the mucosal surface of the stomach and duodenum called Gastric or duodenal ulcer (Asali *et al.*, 2018). But gastric ulcer is a sore or hole in the lining of the stomach, and it is a mucosal defect that reaches the muscularis mucosa (Abelwahab and Abourehab, 2012). In general, gastric ulcers are the results of an imbalance in several endogenous aggressive factors, including hydrochloric acid, pepsin, refluxed bile, leukotrienes and reactive oxygen species (ROS), several exogenous factors including non-steroidal anti-inflammatory drugs (NSAIDs), stress, alcohol and Helicobacter pylori infection and protecting mechanism of the gastric mucosa such as mucous, PGE2, and PGI2.

Non-steroidal anti-inflammatory drugs NSAIDs including Aspirin, Indomethacin are effective in the treatment of a variety of acute and chronic pain conditions (Boltin & Niv, 2014).

Gastric ulcer is a very conventional disease in the world, Statistics from all sources indicate 10% or more of adult population are affected within their life time (Vyawahare *et al*., 2009), The prevalence of gastric ulcer is 2.4% in the Western population (groenen *et al.,* 2009) and annual incidence rates range from 0.10% to 0.19% (sung *et al.,* 2015). In certain regions of Mainland China, the prevalence of gastric ulcer is as high as 6.07% in the general population, and 22.5% of patients with gastrointestinal symptoms have gastric ulcer (Dong *et al.,* 2012). Higher incidence usually occurs in people who smoke, use non-steroidal anti-inflammatory drugs (NSAIDs), or consume alcohol (Ali *et al.,* 2023). The re-occurrence rate is as high as 60% (Fujino *et al.,* 2012). Gastric ulcer has a significant economic impact; Average annual medical costs are $23,819 for gastric ulcer in the United States (Song et al., 2013). In South Korea, the annual medical costs for gastric ulcer range from $959.6 to $2,553.10 (Ford *et al.,* 2004).

According to the latest WHO data published in 2020 Gastric ulcer Disease Death in Nigeria reached 5,123 or 0.26% 0f total deaths. The age adjusted is 6.26 per 100,000 of population ranks Nigeria 31st in the world (WHO, 2020).

Treatment of gastric ulcer is basically the use of proton pump inhibitors (PPIs) (i.e., omeprazole, esomeprazole, lansoprazole, and pantoprazole) and Histamine 2 receptor antagonist (H2RAs) such as cimetidine, cimetidine. (Masclee *et al.,* 2014). However, some of these drugs are expensive and have many side effects, therefore, the health-promoting and disease-preventing properties from a plant-derived compound such as cinnamon are developed.

Cinnamon also called *Cinnamomum verum or zeylanicum* scientifically is a common spice used around the world for several centuries, It is gain from the inner bark of genus Cinnamomum and family Lauraceae, which have used as a popular spice, condiment and flavoring. It is obtained from every part of the cinnamon tree, including the bark, flowers, fruits, leaves, and roots (Ranasinghe *et al*., 2013). It is traditionally used for many diseases such as diabetes mellitus, arthritis, and it also has effect as anti-inflammatory, anti-ulcerative, anti-bacterial, anti-septic, anti-tumor, anti-diabetic, hepatoprotective and anti-mutagenic (Bodiba and Lall, 2018; Muhammad and Dewettinck, 2018).

The use of low-dose aspirin (LDA, 75–325 mg/day) has continually increased during recent decades (Baigent *et al.,* 2009). Beside its cardiovascular effect, aspirin has been proved to be beneficial for cancer prevention, which probably further increases its use (Cuzick *et al.*, 2015) the risk of harmful side effects, especially gastrointestinal (GI), limits the general benefit of aspirin use, LDA decreases the incidence of cardiovascular events by 12% (Baigent *et al.,* 2009) but the incidence of serious GI adverse events is approximately one case per 1000 persons/year in overall population (Cuzick *et al.*, 2015). Despite its relatively low risk for GI bleeding, the millions of aspirin users worldwide determine an important increase in the number of drug related GI complications (Garrow and Delegge, 2010). In order to minimize the risk of bleeding among patients treated with LDA a number of recommendations were developed, current therapeutic of gastric ulcers largely rely on Western medicine, clinical evaluation of this drugs, such as PPIs and H2R as well as triple option has shown incidence of relapses, side effects and drug interactions development of tolerance, thus making their efficacy debatable.

2. MATERIALS AND METHODS

Equipment

cages, clinical hand gloves, camera, cotton wool, stop watch, syringe, water, weighing balance, EDTA bottles, oral cannula, dissecting set, pipette spectrophotometer, Weighing balance, Micropipette, Water bath, Deep freezer, Centrifuge machine..

Drugs and reagent

Aspirin, Trichloroacetic acid (TCA) dimethylaminobenzaldehyde, epinephrine, acetyl acetone, bovine serum albumin (BSA), gallic acid, aluminum chloride, quercetin and thiobarbituric acid (TBA), Distilled water, ketamine, diazepam, sucrose.

Collection of the plant materials

Cinnamomum verum was purchased from Arabian-Syrian Company, South City Plaza, Selangor, Darul-Ehsan, Malaysia.

Experimental animals

A total of 40 male Wistar rats weighing 120-160g were sourced from the animal house, Department of Human physiology, Ahmadu Bello University Zaria. The rats were allowed to acclimatize to the laboratory conditions and kept on standard rodent laboratory diets and access to unlimited supply of drinking water, except for the short fasting period where the drinking water was still free access but no food supply provided 12hrs prior to treatment.

Methodology

Preparation of cinnamon aqueous extracts

The extraction of cinnamon was done in the Pharmacological Department of the Faculty of Pharmacy, Ahmadu Bello University Zaria, Kaduna State Nigeria. The aqueous bark extract of *Cinnamomum verum* was prepared according to the method of Abdeen *et al*. (2018), with some modifications. Cinnamon bark 500 g was grinded to powder form to reduce its size. The powder form of cinnamon bark was dissolved in 3 litres of water for 24 hours to avoid fermentation. The dissolved *Cinnamomum verum* bark was then filtered and the residue was removed. The water content was evaporated so as to get the solid aqueous form of cinnamon

Where concentration of the aqueous root bark extract = 100mg/ $cm^{3.}$

Toxicity study of the extract

Determination of acute toxicity LD_{50} was carried out using the method of Lorke (1983). Lorke's method was employed when less than half of the grouped rats survived; twelve rats were used for acute toxicity testing for the determination of LD_{50} in two phases (Lorke, 1983). In the initial phase, nine rats were divided into three groups (A, B, and C) of 3 rats each. They were orally treated with 10, 100 and 1000mg/kg of the extract. The rats were observed for 24hours for any mortality. In the second phase, the rats were grouped into three groups (A, B, and C) of one rat each and orally treated with the extract at varying doses (1600, 2500 and 5000mg/kg). The animals were observed for 24hours and the final LD_{50}value were determined from the highest dose that produces no mortality and lowest dose that produced mortality in both phases. The LD_{50} is calculated using the formula:$LD_{50} = \sqrt{D_0} \times D_{100}$

Where:D_0 = Highest dose that gave no mortalityD_{100} = lowest dose that produced mortality(Oecd, 2008)

Experimental Design

Fourty(40) male wistar rats aged 9-10 weeks weighing 120-140g were used for the study, there were divided into seven groups (n=7). The treatment groups T1 and T2 received the cinnamon extract with doses 400mg/kg and 800mg/kg, respectively and 75mg/kg Aspirin orally via a stainless-steel intubation needle for 45days. Two doses were given at 08:00h and 16:00h. At the same time; normal control group were given distilled water (10 mL/kg) and ulcerated control group were given Aspirin 75mg/kg, a positive control group were given cimitidine at 50 mg/kg (Alkofahi *et al*., 2012). Experimental animals in the study were treated in accordance with the National Protection Laws of Animal Welfare.

Table 2.0 EXPERIMENTAL DESIGN

GROUPING		**TREATMENT**
Group I	Normal Control Group (DW)	Distilled Water (10 mL/kg)
Group II	Experimental control group (CN)	Cinnamon 400mg/kg b.w
Group III	Ulcerated control group (ASP)	Aspirin 75mg/kg b.w
Group IV	Experimental group (ASP + CN 400mg)	ASP + 400mg/kg b.w aqueous cinnamon extract
Group V	Experimental Group (ASP + CN 800mg)	ASP + 800mg/kg b.w aqueous cinnamon extract
Group VI	Experimental Group (ASP + CM)	ASP + Cimetidine 50 mg/kg b.w

Sample collection

On the 28th day, the rats were fasted for 48 hours for the collection of gastric juice according to the method of Shay *et al.,* (1954). Under anesthesia with ketamine 75mg/kg and diazepam 5 mg/kg for pyloric ligation, the abdomen of the rats was shaved and a midline incision made extending 2 cm downwards from the xyphoid, the junction between the pylorus and the duodenum was identified, gently picked up and a pyloric ligature was applied using silk thread. In satisfactorily prepared animals, the abdominal wall was then closed by interrupted sutures; the abdominal wound was cleaned with physiological saline, dried and covered with a solution of flexible collodion. Four hours later, and under anesthesia, the abdomen was again opened, The stomach was harvested and washed in physiological saline and dried, An opening was made along the greater curvature and the gastric juice was collected using test tube, After centrifugation at 2000 x g for 5 min, the supernatant was collected, Analysis was carried out for pH, Pepsinogen concentration and mucous contents.

Gastric secretion studies



Plate III: pyloric ligation (snapped by self, 2023)

Determination of mucous content

To 1g of stomach tissue, 5mls of Alcian Blue with 0.25M sucrose and 0.05M sodium acetate, adjusted to pH 5.8 with hydrochloric acid was added and incubated for about 2 hours at room temperature. This was gently rinsed and decanted as described by Corney *et al.,* (1974). The uncompleted dye was removed by two successive washes at 15 and 45 minutes in 0.25M sucrose. Thereafter, the mucosa was inversed in 10ml of 0.5M Magnesium Chloride. The resulting blue solution was shaken briefly with equal volume of diethyl ether and absorbance of the aqueous phase was measured at 605nm using spectrophotometer. The absorbance of each solution was then used to calculate the various concentrations of dye. The weight of dye (expressed in mg) was obtained using a standard curve, where the weight of dye was expressed over the weight of the stomach, to give the weight of mucus secretion (Onwuchekwa and Oluwole, 2015).

Determination of pepsin content

One ml from various concentrations of bovine pepsin, ranging from 0.1-1.0 mg/100 ml in 0.1N HCl, were gently transferred to a test tube and incubated for 30 min with 3.9 ml of the substrate in a water bath at 37^{o}C. Then, 10 ml of trichloracetic acid (TCA) was added and the tubes allowed standing for 10 min and filtered using Whatman filter paper No. 1. Accordingly, Blanks were accordingly made for each concentration by adding 10 ml of TCA before the addition of the enzyme. Duplicate determinations were performed for each enzyme concentration. The optical density of the filtrate was then determined and measured at 280 nm wavelength. A standard curve was plotted, from which pepsin content of gastric secretion was extrapolated (Hawk *et al.*, 1960).

To 0.2 ml of centrifuged gastric juice, 3 ml of casein 1 %for each rat test and blank was added. Then 10 ml of 3% trichloracetic acid was also added to the blank to stop enzyme activity. Both blank and test tubes were incubated in water bath at 37^0C for 30 minutes. At the end of incubation period, the tubes were removed from the water bath and enzymatic reaction stopped in the test by adding 10 ml of trichloracetic acid. The solution in the test-tubes was allowed to stand for 10minutes and filtered using No.1 Whatman filter paper. Proteolytic activity was determined from the absorbance readings of the filtrate which was determined at 280 (mp) wave length of ultraviolet light using spectrophotometer (Hawk *et al.*, 1960).

Quantification of ulceration

Degrees of ulceration in the aspirin-treated animals were quantified using the procedure outlined by Szabo and Hollander (1985). Briefly, cleaned stomachs was pinned on a corkboard and ulcers were scored using dissecting microscope with square-grid eyepiece based on grading on a 0–5 scale (depicting severity of vascular congestions and lesions/hemorrhagic erosions) as presented below. Areas of mucosal damage (ulcer rating) were expressed as a percentage of the total surface area of the glandular stomach estimated in square millimeters. Mean ulcer score for each animal were expressed as ulcer index (U.I) and the percent-age of inhibition against ulceration was determined using the expressions:
U.I. = [Ulcerated area/total stomach area] × 100.
%Ulcer inhibition = [U.I. in control − U.I. in test] × 100/U.I. in control.

Score	Remarks
0	Almost normal mucosa
1	Vascular congestion
2	One or two lesions
3	Severe lesions
4	very severe lesions
5	Mucosa full of lesions

Sample collection

At the end of the experiment, the rats were sedated by intraperitoneal injection of ketamine and diazepam at 75mg/kg and 5mg/kg respectively (Molina *et al.*, 2015). Blood samples were collected via cardiac puncture, into plain tubes and separated by centrifugation at 3000 RPM for 10 minutes, The resultant sera was used for the evaluation of oxidative stress biomarkers.



Plate II: Blood sample collection via cardiac puncture (snapped by candidate, 2023

Evaluation of oxidative stress biomarkers

About 1g of cleaned gastric tissues was homogenized in 5mls of phosphate buffer and centrifuged. The supernatant was used to detect for levels of malondialdehyde (MDA), super¬oxide dismutase (SOD), catalase (CAT), and glutathione peroxidase (GPx) by spectrophotometry.

Preparation of phosphate buffer solution

0.1 M Phosphate Buffer at pH 7.4
0.1 M NaH2PO4.H2O (Sodium Dihydrogen Orthophosphate)
Amount (g) = Molarity (M0) × Molecular Weight (Mw) × Required Volume (Rv)/1000
= 0.1 × 137.99 × 200/1000
= 3.56g

Estimation of superoxide dismutase activity

The enzyme activity was determined by the method described by Kono (1978)
Principle: The principle works on the ability of superoxide dismutase to inhibit auto oxidation of adrenaline when adjusted to pH 10.2.
Reagents:
0.05M Carbonate Buffer: 14.3g of Na2CO3 and 4.2g of NaHCO3 was dissolved in distilled water and made up to 1000 ml in a volumetric flask. The buffer was gradually adjusted until the pH 10.2.
0.3Mm Adrenaline: Fresh solution was prepared by dissolving 0.01g of adrenaline in 17 ml of distilled water.
Procedure:
0.1 ml of the sample was diluted in 0.9 ml of distilled water to make 1:10 dilution of serum. An aliquant mixture of 0.2 ml of the diluted serum was also added to 2.5 ml of 0.05 M carbonate buffer. This was monitored for reaction starting with the addition of 0.3 mm of 0.3 mM adrenaline. The reference mixture now contains 2.5 ml of 0.05 M carbonate buffer, 0.3 ml of 0.3mM adrenaline and 0.2 ml of distilled water. Absorbance was then measured over 30s up to 150s at 480nm.
Calculation:
Increased in absorbance per minute = (A5- A1)/ 2.5
% inhibition = 100- increase in absorbance for substrate/increase in absorbance of blank ×100.
50% inhibition of adrenaline oxidation → IU
% Inhibition of adrenaline oxidation → ×U
1 unit (U) of SOD activity was the quantity of SOD required to elicit 50% of the oxidation of adrenaline to the serum in 1 minute.

Estimation of catalase activity

Catalase activity was assessed by the method described by Bansal *et al.* (2018) The assay mixture consisted of 0.05 ml sample, 1.0 ml hydrogen peroxide (0.019 M), 1.95 ml phosphate buffer (0.05 M, pH 7.0), in a final volume of 3.0 ml. Changes in optical density were recorded at 240 nm. Using the millimolar extinction coefficient of H2O2 (0.07 mM), catalase activity was calculated and expressed as µM of H2O2 decomposed per minute per milligram protein.

Determination of lipid peroxidation

Principle: This was based on generation of peroxide intermediates which release MDA upon cleavage, a product which react with TBA.
Reagents:
0.67% Thiobarbituric Acid (TBA), 1 % Trichloroacetic Acid (TCA), Hydrochloric Acid.
Procedure:
Malondialdehyde content, a marker of lipid peroxidation, was assessed in the sample by a method previously described by Wills (1996). A mixture consisting of 0.5 ml of Tris-HCL and sample (0.5 ml) was incubated for 2 h at 37°C. To this incubated mixture, 1 ml of 10% trichloroacetic acid was added and centrifuged for 10 min at 1000g. Thereafter, 1 ml of thiobarbituric acid was added to 1 ml of supernatant obtained after centrifugation and was kept in boiling water for 10 min. Finally, on cooling, 1 ml of distilled water was added and the absorbance was measured at 532 nm. TBARS was calculated using the molar extinction coefficient of 1.56 × 105 M−1 cm−1 and was expressed as nanomole of malondialdehyde per milligram protein.

Histological Examination

Gastric tissue that was obtained from each group fixed in 10% formalin for 24 hours. The specimens were embedded in paraffin block and slicing (3- 5 mm) then was stained by Hematoxylin and Eosin. The histological sections were observed by light microscope and photographed (100x magnification).

Statistical analysis

Results were expressed as mean ± standard error of the mean (SEM). Data were analyzed using one-way analysis of variance (ANOVA) followed by *Tukey's post-hoc* test for multiple comparison. All analyses were done using SPSS version 20 and Graph Pad Prism Version 8.0.2 was used in drawing the charts. P-value less than 0.05 were considered statistically significant.

3.0 RESULTS

Acute Toxicity Test

In the initial phase of the determination of acute toxicity, mortality and toxic symptoms were not observed when the aqueous bark extract of *Cinnamomum verum* was administered orally to the experimental rats (Table 3.1). In the second phase, no mortality was observed although some rats exhibited symptoms of weakness (Table 3.2).

Table3.1: Phase I LD50 (oral, rat) of the aqueous bark extract of Cinnamomum verum

Doses(mg/kg)	Mortality
10	0/3
100	0/3
1000	0/3

Table 3.2: Phase II LD50 (oral, rat) of the aqueous bark extract of Cinnamomum verum

Doses (mg/kg)	Mortality
1600	0/1
2500	0/1
5000	0/1

3.2 Effects of Aqueous Extract of Cinnamon on Aspirin-Induced Ulcer in Wistar Rats

3.1.1. Results of ulcer score and ulcer index

Figure 3.1 shows ulcer score, Comparison between DW 1 ml/kg (2.0 ± 1.0) and groups administered with CN 400 mg/kg (1.5 ± 0.5), ASP (5.0 ± 0.0), ASP + CN 400 mg/kg (0.0 ± 0.0), ASP + CN 800 mg/kg (1.0 ± 1.0) and ASP + CIM 50 mg/kg (2.5 ± 0.5) showed no statistically significant difference in ulcer score (Figure 4.2). However, Group administered with ASP significantly showed increase in ulcer score compared to ASP + CN 400 mg/kg, and ASP + CN 800 mg/kg (Figure 4.1).

As shown in Figure 3.2, a statistically significant ($p < 0.05$) increase in ulcer rating/index was observed between distilled water (DW) 1 ml/kg group (3.5 ± 0.5) compared to Aspirin (ASP) 75 mg/kg group (10.0 ± 0.0**)** at $p = 0.013$. However, comparison between the DW group and groups administered with cinnamon (CN) 400 mg/kg (4.0 ± 1.0), ASP + CN 400 mg/kg (0.0 ± 0.0), ASP + CN 800 mg/kg (1.5 ± 1.5) and ASP + cimetidine (CIM) 50 mg/kg (5.0 ± 1.0) did not show any significant ($P>0.05$) difference. ulcer score was Significantly ($p< 0.05$) increased in the group administered only ASP , but when ASP group was compared to CN 400 mg/kg, ASP + CN 400 mg/kg, ASP + CN 800 mg/kg, and ASP + CIM 50 mg/kg there was a Significant ($p< 0.05$) decreased in ulcer rating as shown in table 4.2.

However, ASP + CN 400 mg/kg significantly ($p < 0.05$) decreased ulcer rating more than the group administered with standard drug cimetidine (ASP + CIM 50 mg/kg).

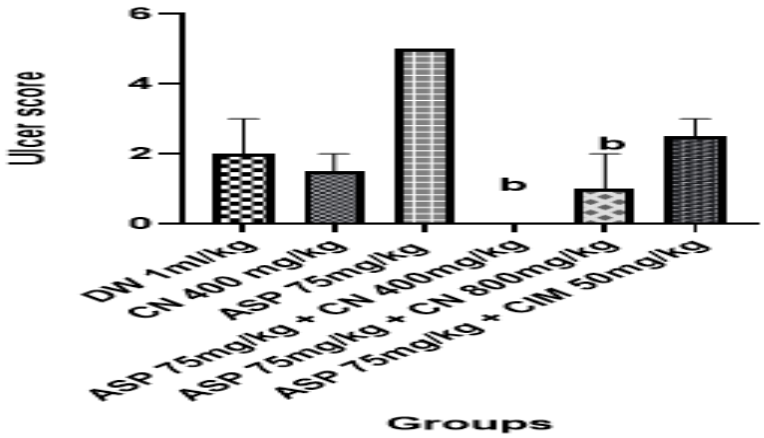


Figure 3.1: Effects of Aqueous Extract of Cinnamon on Ulcer Score in Wistar Rats

[b]Statistically significant compared to DW, ASP 75 mg/kg, and ASP + CIM 50 mg/kg groups respectively ($p < 0.05$). DW: Distilled Water, CN: Cinnamon, ASP: Aspirin, CIM: Cimetidine.

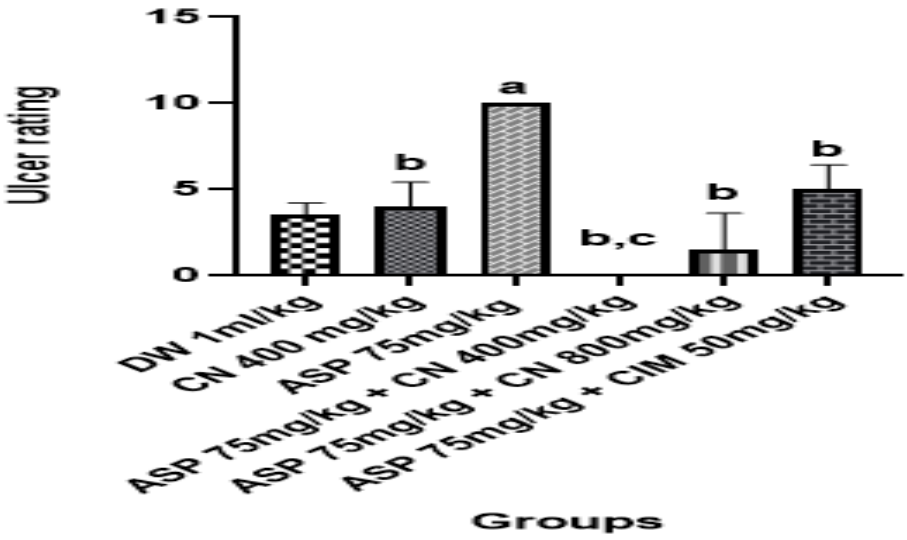


Figure 3.2: Effects of Aqueous Extract of Cinnamon on Ulcer Rating in Wistar Rats

[a,b,c]Statistically significant compared to DW, ASP 75 mg/kg, and ASP + CIM 50 mg/kg groups respectively. DW: Distilled Water, CN: Cinnamon, ASP: Aspirin, CIM: Cimetidine.

3. Effects of Aqueous Extract of Cinnamon on Volume and pH of gastric juice in Aspirin-Induced Ulcer in Wistar Rats

The result on volume and pH of gastric juice in aspirin-induced ulcer in wistar rats undergone six weeks. There was no statistically significant ($P<0.05$) difference in volume and pH of gastric juice when the normal control group (DW) (1.3 ± 0.2 ml) was compared with CN 400 mg/kg (1.2 ± 0.3 ml), ASP (1.5 ± 0.2), ASP + CN 400 mg/kg (1.6 ± 0.5 ml), ASP + CN 800 mg/kg (1.5 ± 0.2 ml) and ASP + CIM 50 mg/kg (0.9 ± 0.2 ml), (Table 4.2). Similarly, there was also no significant difference between when ASP alone was compared to ASP + CN 400 mg/kg, ASP + CN 800 mg/kg and ASP + CIM 50 mg/kg, (Table 4.3).

3.3. Effects of Aqueous Extract of Cinnamon on Pepsin and Mucous Concentrations of gastric juice in Aspirin-Induced Ulcer in Wistar Rats

The result on pepsin and mucous concentrations of gastric juice in aspirin-induced ulcer in wistar rats undergone after six weeks. As shown in Table 3.4, there was no statistically significant difference observed in pepsin concentration between DW (2.5 ± 0.4 mg/ml) and groups administered with CN 400 mg/kg (2.0 ± 0.2), ASP (2.0 ± 0.3 mg/ml), ASP + CN 400 mg/kg (2.1 ± 0.4 mg/ml), ASP + CN 800 mg/kg (3.2 ± 0.6 mg/ml) and ASP + CIM 50 mg/kg (2.8 ± 0.3 mg/ml), Similarly, no significant difference was observed between group administered with ASP compared to ASP + CN 400 mg/kg, ASP + CN 800 mg/kg and ASP + CIM 50 mg/kg.

Result of mucous concentration showed no statistically significant difference between DW 1 ml/kg (1.7 ± 0.2 mg/ml) and groups administered with CN 400 mg/kg (1.2 ± 0.2 mg/ml), ASP (1.3 ± 0.1 mg/ml), ASP + CN 400 mg/kg (2.2 ± 0.3 mg/ml), ASP 75 + CN 800 mg/kg (1.2 ± 0.2 mg/ml) and ASP + CIM 50 mg/kg (1.2 ± 0.3 mg/ml) (Table 4.1). Similarly, no significant difference was observed between ASP 75 compared to ASP 75 + CN 400 mg/kg, ASP 75 + CN 800 mg/kg and ASP 75 + CIM 50 mg/kg, (Table 4.2).

Table 3.3: Effects of Aqueous Extract of Cinnamon on Volume of Acid and pH in Wistar Rats

Groups	Volume of Acid (ml) Mean ± SEM	pH Mean ± SEM
DW 1 ml/kg	1.3 ± 0.2	3.5 ± 0.1
CN 400 mg/kg	1.2 ± 0.3	5.4 ± 1.3
ASP 75 mg/kg	1.5 ± 0.2	5.1 ± 0.7
ASP 75 mg/kg + CN 400 mg/kg	1.6 ± 0.5	5.2 ± 0.3
ASP 75 mg/kg + CN 800 mg/kg	1.5 ± 0.2	3.8 ± 0.5
ASP 75 mg/kg + CIM 50 mg/kg	0.9 ± 0.2	5.2 ± 0.4

Mean difference was not statistically significant ($p > 0.05$), using one-way ANOVA and *Tukey's post hoc*. DW: Distilled Water, CN: Cinnamon, ASP: Aspirin, CIM: Cimetidine

Table 3.4: Effects of Aqueous Extract of Cinnamon on Pepsin and Mucos Concentrations in Aspirin-induced ulcers in Wistar Rat

Groups	Pepsin Concentration (mg/ml) Mean ± SEM	Mucos Concentration (mg/ml) Mean ± SEM
DW 1 ml/kg	2.5 ± 0.4	1.7 ± 0.2
CN 400 mg/kg	2.0 ± 0.2	1.2 ± 0.2
ASP 75 mg/kg	2.0 ± 0.3	1.3 ± 0.1
ASP 75 mg/kg + CN 400 mg/kg	2.1 ± 0.4	2.2 ± 0.3
ASP 75 mg/kg + CN 800 mg/kg	3.2 ± 0.6	1.2 ± 0.2
ASP 75 mg/kg + CIM 50 mg/kg	2.8 ± 0.3	1.2 ± 0.3

Mean difference was not statistically significant ($p > 0.05$), using one-way ANOVA and *Tukey's post hoc*. DW: Distilled Water, CN: Cinnamon, ASP: Aspirin, CIM: Cimetidine

3.4 Effects of Aqueous Extract of Cinnamon on Oxidative Stress Biomarkers in Aspirin-Induced Ulcer in Wistar Rats

4.4.1 Results of superoxide dismutase enzyme activity

As shown in Figure 3.3, there was no statistically significant (P>0.05) difference observed in SOD activity between DW (63.6 ± 1.2 U/ml) and groups administered with CN 400 mg/kg (63.7 ± 0.7), ASP (61.8 ± 0.6 U/ml), ASP + CN 400 mg/kg (61.5 ± 1.0 U/ml), ASP + CN 800 mg/kg (60.5 ± 1.8 U/ml) and ASP + CIM 50 mg/kg (58.0 ± 2.4 U/ml), Similarly, no significant (P>0.05) difference was observed between ASP compared to ASP + CN 400 mg/kg, ASP + CN 800 mg/kg and ASP + CIM 50 mg/kg.

3.4.2 Results of catalase enzyme activity

Comparison between DW (45.5 ± 6.8U/mg protein) and groups administered with CN 400 mg/kg (34.3 ± 12.9 U/mg protein), ASP (33.3 ± 8.2 U/mg protein), ASP + CN 400 mg/kg (134.6 ± 24.7 U/mg protein), ASP + CN 800 mg/kg (87.2 ± 32.0 U/mg protein) and ASP + CIM 50 mg/kg (108.9 ± 28.9 U/mg protein) showed no statistically significant (P>0.05) difference in CAT enzyme activity, (Figure 3.4). However, ASP significantly (P<0.05) decreased CAT activity compared to ASP + CN 400 mg/kg group. Also, ASP + CN 400 mg/kg significantly increased CAT activity compared to CN 400 mg/kg. But no statistical significant (P>0.05) difference was observed between ASP compared to ASP + CN 800 mg/kg and ASP + CIM 50 mg/kg (Figure 3.4).

3.4.3 Results of Malondialdehyde level

As shown in Figure 3.5, there was no statistically significant difference observed in MDA level between DW 1 ml/kg (68.9 ± 1.9um/ml) and groups administered with CN 400 mg/kg (68.5 ± 4.9), ASP (75.4 ± 4.3 9um/ml), ASP + CN 400 mg/kg (63.8 ± 1.6 9um/ml), ASP + CN 800 mg/kg (59.9 ± 1.1 9um/ml) and ASP + CIM 50 mg/kg (63.5 ± 1.9 9um/ml). However, group administered with ASP significantly increased MDA level compared to group administered with ASP + CN 400 mg/kg, ASP + CN 800 mg/kg and ASP + CIM 50 mg/kg.

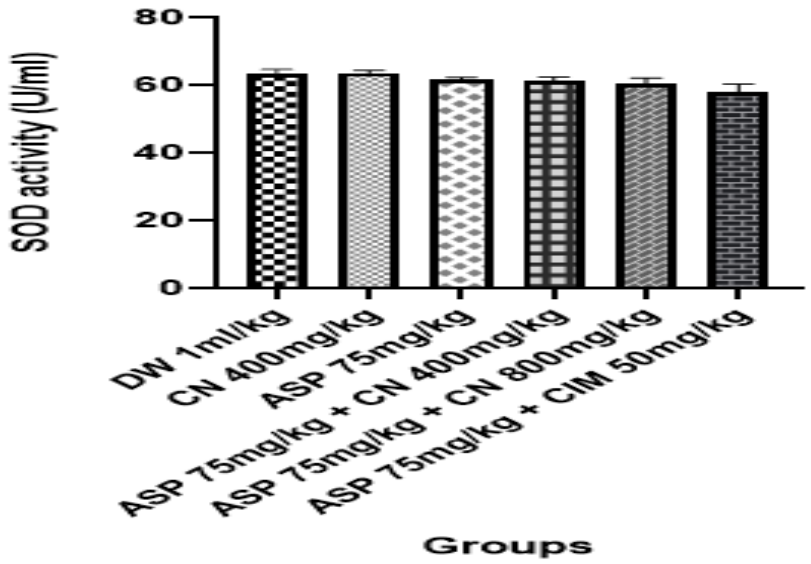


Figure 3.3: Effects of Aqueous Bark Extract of Cinnamon on Superoxide Dismutase Enzyme Activity on Aspirin-Induced Ulcer in Wistar Rat

Mean difference was not statistically significant ($p > 0.05$), (n=5), using one-way ANOVA and *Tukey's post hoc*, Graph Pad Prism version 8.0.2. DW: Distilled Water, CN: Cinnamon, ASP: Aspirin, CIM: Cimetidine, SOD: Superoxide Dismutase

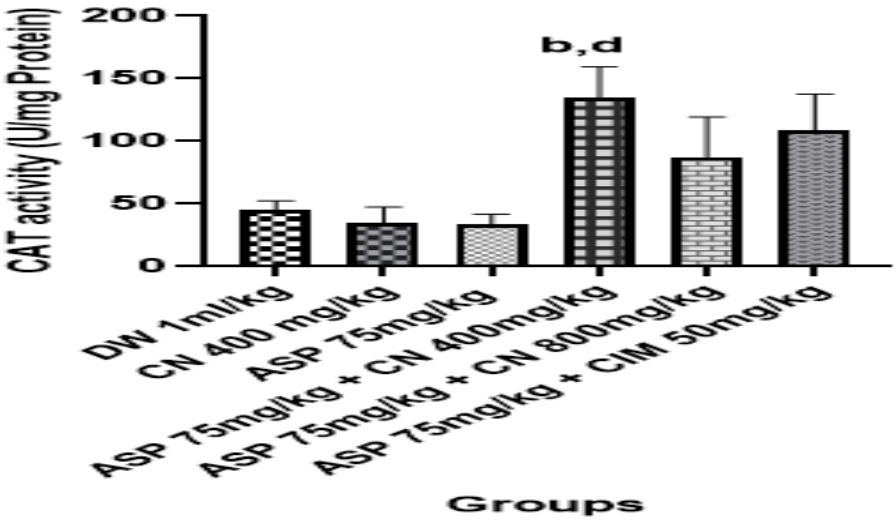


Figure 3.4: Effects of Aqueous Bark Extract of Cinnamon on Catalase Enzyme Activity on Aspirin-Induced Ulcer in Wistar Rat

[bd]Statistically significant compared to ASP 75 mg/kg, and CN 400 mg/kg groups, respectively, ($p < 0.05$), (n=5) using one-way ANOVA and *Tukey's post hoc*, Graph Pad Prism version 8.0.2. DW: Distilled Water, CN: Cinnamon, ASP: Aspirin, CIM: Cimetidine, CAT: Catalase

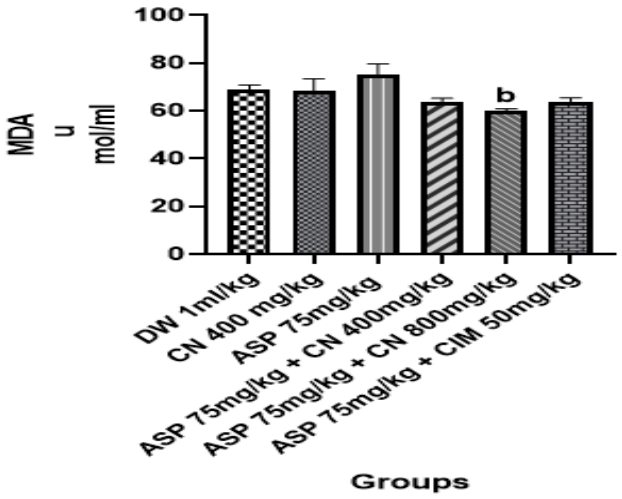


Figure 3.5: Effects of Aqueous Bark Extract of Cinnamon on Malondialdehyde Level on Aspirin-Induced Ulcer in Wistar Rat

[b]Statistically significant compared to ASP 75 mg/kg group, ($p < 0.05$), (n=5) DW: Distilled Water, CN: Cinnamon, ASP: Aspirin, CIM: Cimetidine, MDA: Malondialdehyde

3.5 Assessment of the Effects of Aqueous Extract of Cinnamon on histology of gastric mucosal Tissues on Aspirin-Induced Ulcer in Wister Rats.

Plate 3.1, plate 3.2, plate 3.4, plate 3.5 and plate 3.6 showed the pho**to**micrograph of gastric mucosa of rat in normal control group (DW), cinnamon control (CN), ASP 75mg/kg + CN 400MG/KG, ASP + CN 800MG/KG, ASP + cimetidine respectively. The DW group showed intact surface epithelial cells with well-defined mucosal and submucosal linings, undamaged gastric pits. Aspirin control group (ASP) Showed necrosis and deep ulceration with distortion of gastric pits; while ASP and CN 400mg group showed slight necrosis. Other groups: ASP + CN 800MG/KG, ASP + cimetidine showed normal mucosa.

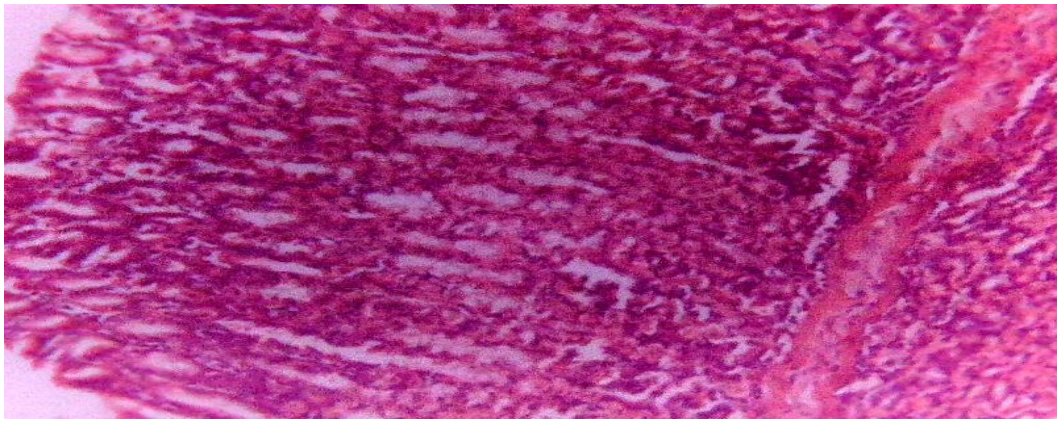


PLATE IV: Normal Control Group: Control Group Received Distilled Water (10 Ml/Kg), Shows Normal Mucosa, Mag X 400. H &E Stain.

PLATE V: Cinnamon Control Group: Cinnamon 400mg/Kg. Mag X400, H&E Stain

PLATE VI: Ulcerated control group: Aspirin 75mg/kg, shows deep mucosa ulceration (DMU), Mag x400, H&E stain

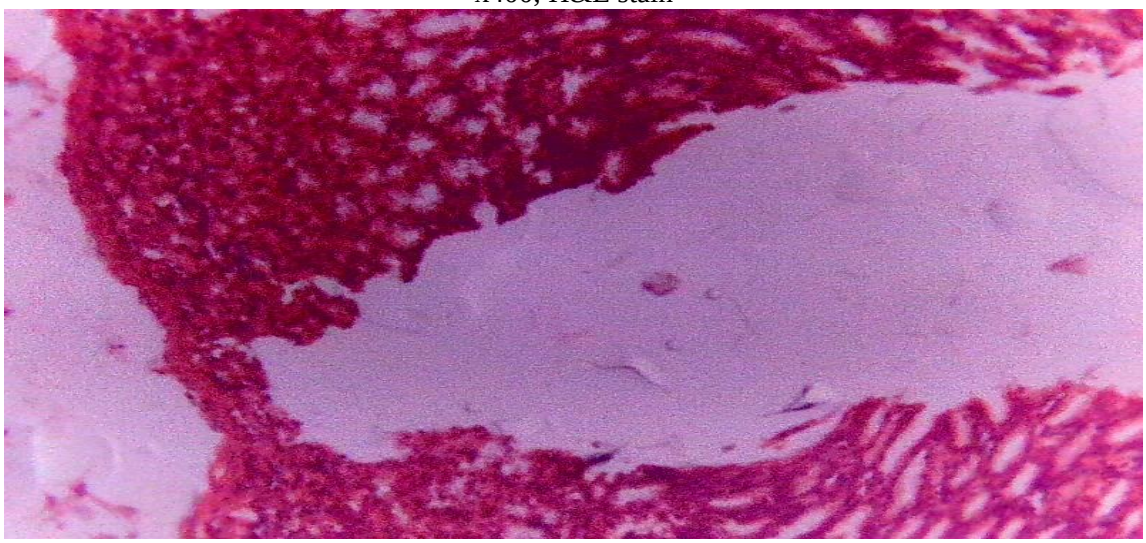


PLATE VII: Treatment Group 1: Received 400mg/Kg Aqueous Cinnamon Extract. Mag X400, H&E Stain

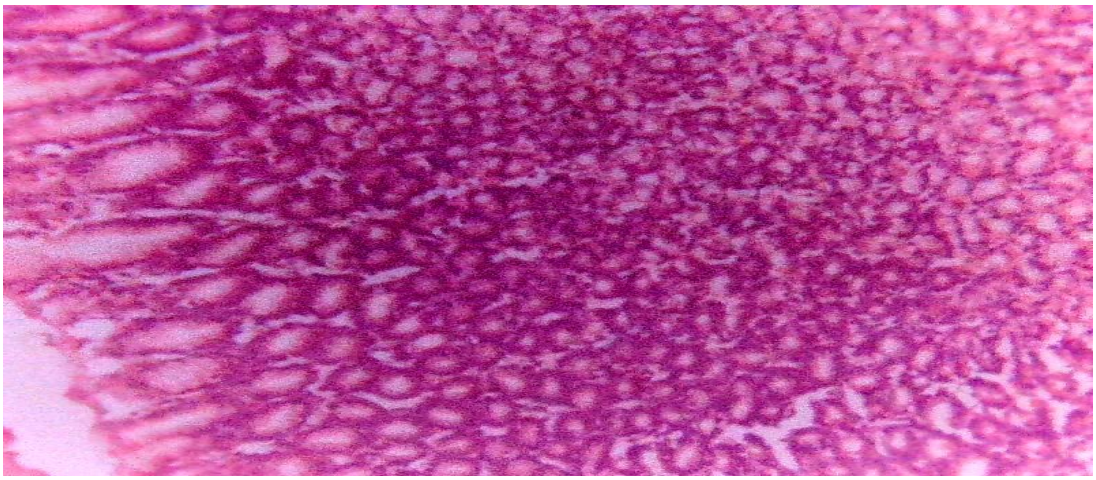


PLATE VIII: Treatment Groups 2: Received 800mg/Kg Aqueous Cinnamon Extract, Shows Normal Tissue. Mag X400, H&E Stain

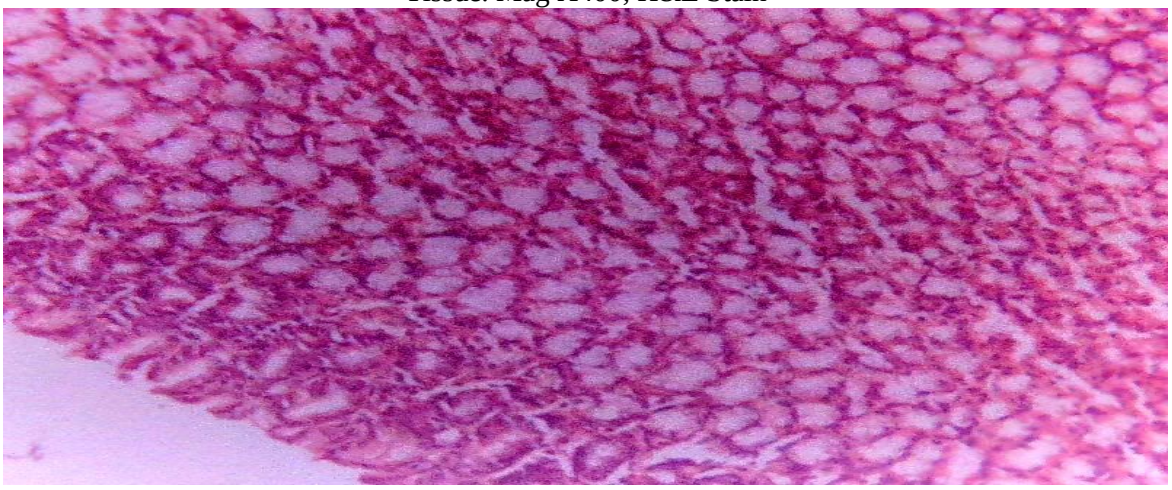
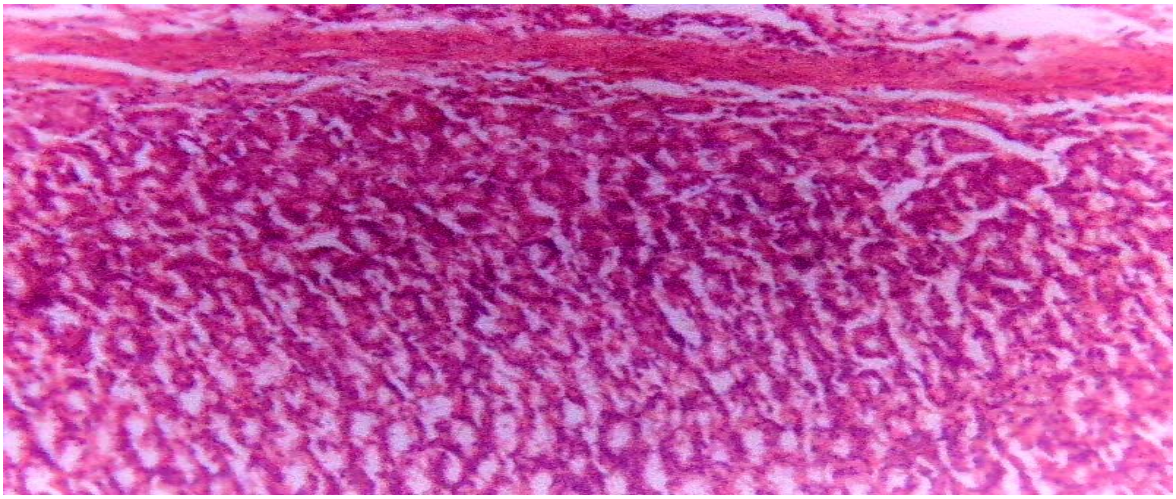


PLATE IX: Positive Control Group: Cimetidine 50 Mg/Kg, Shows Normal Tissue. Mag X400, H&E Stain.



5.DISCUSSION

Non-steroidal anti-inflammatory drugs (NSAIDs) such as aspirin, which is frequently used in daily life, interfere with the synthesis of prostaglandin and inhibit its release; it also increases the reabsorption of the hydrogen ions, thereby increasing the acid release (Burke *et al*., 2016). This study investigated the effects of aqueous extract of *Cinnamomum verum* on Gastric ulcers induced by long-term low-dose aspirin on Gastric ulcer in male Wistar rats.

Aspirin significantly increased ulcer scores and rates compared to groups treated with cinnamon and cimetidine. This observation supports previous findings by Szabo (1995) and Al-Harbi (1997), who reported that non-steroidal anti-inflammatory drugs (NSAIDs) such as aspirin damage gastric tissues by suppressing prostaglandin synthesis through cyclooxygenase (COX) inhibition. Interestingly, cinnamon at a dose of 400 mg/kg provided superior protection against ulceration compared to cimetidine, as it significantly reduced ulcer scores and rates. This aligns with the findings of Mohammed (2014), who demonstrated that cinnamaldehyde, a key component of *Cinnamomum zeylanicum*, has gastric cytoprotective and anti-secretory properties, enhancing gastric mucosal protection and promoting ulcer healing. Similarly, Tanaka *et al*., (2017) indicated that cinnamon's gastroprotective effects might be mediated through the biosynthesis of prostaglandins, which play a vital role in gastric mucosal defense. Gastric Juice Parameters. The study showed no significant differences in pepsin and mucus concentrations among groups administered distilled water, aspirin, cinnamon, and cimetidine. This finding contradicts Voutilainen *et al*., (2001), who suggested that prostaglandins protect the gastrointestinal mucosa by increasing mucus and bicarbonate secretion.

Studies by Mathew and Abraham (2016) revealed that volatile cinnamon oil containing compounds such as cinnamaldehyde and caryophyllene enhances mucus levels at lower doses (100–200 mg/kg). The absence of significant effects on mucus and pepsin concentrations in this study may indicate that the protective effect of cinnamon at 400 mg/kg is mediated through other mechanisms, such as antioxidant and anti-inflammatory pathways, rather than changes in gastric juice parameters.

Oxidative Stress Biomarkers. The study revealed that aspirin significantly reduced superoxide dismutase (SOD) and catalase (CAT) activities in the stomach, contributing to oxidative stress. This finding is consistent with previous research by El-Missiry *et al*., (2001), Mizoguchi *et al*. (2001), and de la Lastra *et al*., (2002), which reported that NSAIDs induces oxidative stress by depleting antioxidant enzyme activity. Cinnamon treatment, however, significantly increased CAT and SOD activity, suggesting its ability to mitigate oxidative stress. Barboza *et al*., (2018) reported that eugenol, a key component of cinnamon, enhances antioxidant enzyme activity and reduces inflammatory responses by inhibiting neutrophil infiltration. These results indicate that cinnamon's antioxidant properties play a crucial role in protecting gastric tissues from aspirin-induced damage.

Lipid Peroxidation. Aspirin significantly increased malondialdehyde (MDA) levels, a marker of lipid peroxidation, indicating enhanced oxidative stress. This finding supports the observations of Tankam *et al*., (2013), who noted increased MDA levels in NSAID-induced gastric ulcers. Cinnamon treatment reduced MDA levels while increasing total antioxidant capacity, consistent with Ranasinghe *et al*., (2023), who demonstrated that cinnamon's antioxidant properties reduce oxidative stress and enhance the body's natural defense mechanisms. These findings highlight cinnamon's potential to protect gastric tissues by preventing lipid peroxidation and strengthening antioxidant defenses.

Histological evaluation of stomach tissues revealed that aspirin caused severe mucosal ulceration in the ulcerated control group, while cinnamon-treated groups exhibited normal gastric mucosa. This is consistent with findings by El-Metwally (2014), who reported cinnamon's protective effect on gastric tissues through its ability to enhance mucosal integrity.

The mucosal protection observed in cinnamon-treated groups may be attributed to its inhibition of neutrophil infiltration and apoptosis, as suggested by Barboza *et al.*, (2018). Additionally, the reduction in mucosal damage could be linked to cinnamon's ability to enhance prostaglandin biosynthesis, as reported by Gomez-Guzman *et al.*, (2021).

6. Conclusion

The study concluded that *Cinnamomum verum* extract has significant gastroprotective effects in alleviating aspirin-induced gastric ulcers in male Wistar rats. The findings showed that cinnamon extract reduced ulcer scores and ulcer rates, promoted antioxidant activity by increasing catalase levels, and decreased malondialdehyde levels, indicating reduced oxidative stress. Additionally, the histological analysis revealed that cinnamon preserved the gastric mucosa compared to aspirin-treated groups. These results highlight the ability of cinnamon to protect the gastric lining through its antioxidant and cytoprotective properties, making it a potential therapeutic option for managing NSAID-induced gastric damage.

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SYNERGISTIC ANTIDIABETIC ACTIVITY OF CINNAMOMUM VERUM AND ANNONA SQUAMOSA ETHANOLIC LEAVE EXTRACTS IN STREPTOZOTOCIN INDUCED DIABETIC WISTAR RATS

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ABSTRACT
Cinnamomum verum has long been a staple in Nigerian culture, often used as a complementary therapy for managing hyperglycemia in diabetes patients.

Similarly, the local Annona squamosa, or sugar apple, is commonly mixed into traditional remedies aimed at combating high blood sugar. However, the specific antidiabetic effects of cinnamon's ethanolic extract when paired with Annona squamosa leaves remain largely unexplored, and there's a lack of studies examining how this combination influences blood glucose levels and insulin production. This study set out to investigate the antidiabetic properties of cinnamon bark and Annona squamosa leaf extracts, both individually and in combination, using streptozotocin-induced diabetic rats as the model. In this pharmacological study, Wistar male and female rats weighing between 125-140g were subjected to hyperglycemia induced by a 60 mg/kg dose of streptozotocin. The rats were divided into groups of six, including both positive and negative control groups, as well as intervention groups that received ethanol extracts at doses of 200 mg/kg and 300 mg/kg over a period of 21 days. S
The findings revealed that all intervention groups showed an increase in insulin levels alongside a decrease in blood glucose levels after the 21-day treatment. One-Way ANOVA test indicated that the rise in insulin levels from the combination of cinnamon bark and Annona squamosa at the 200 mg/kg dose, as well as the Annona squamosa leaf extract at 300 mg/kg, was comparable to that of Glibenclamide ($p = 0.355$). However, the differences in blood glucose level reductions among the groups were not statistically significant. Combination of cinnamon and Annona squamosa leaf extracts demonstrated a promising synergistic effect in managing diabetes, effectively boosting insulin levels and potentially aiding in the control of blood sugar in hyperglycemic conditions. Further research should be carried-out on combined extracts' synergistic effect, especially at the 200 mg/kg dose.
Keywords: Diabetic, *Annona squamosa*, Wistar rat, Glibenclamide

INTERFERENCE-ENHANCED ACOUSTIC GAS SENSING FOR ENVIRONMENTAL MONITORING AND SAFETY APPLICATIONS

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ABSTRACT
This study presents the design and analysis of a compact hybrid acoustic platform for selective toxic gas detection with potential applications in healthcare and biomedical monitoring. The proposed architecture integrates three types of resonant elements closed simple resonators, open simple resonators, and Helmholtz resonators within a one-dimensional acoustic waveguide, enabling strong modal coupling and interference effects. The acoustic response is investigated using the Scattering Matrix Method (SMM), which accurately characterizes the structure's transmission characteristics and resonant behavior. The results reveal the emergence of Fano resonances and Acoustically Induced Transparency (AIT) arising from the interaction and interference between the resonant modes. A comprehensive parametric analysis demonstrates that the resonance frequencies, linewidths, number of resonant peaks, and quality factors can be effectively tuned through the geometrical parameters of the resonators. The resulting high-quality factor resonant states provide enhanced spectral selectivity and enable the detection of small variations in the acoustic properties of the surrounding gaseous medium. Furthermore, the sensitivity of the resonant response to different gases highlights the potential of the proposed platform for non-invasive and compact gas-sensing technologies relevant to healthcare, biomedical monitoring, and breath-analysis applications. These findings establish the proposed hybrid acoustic architecture as a promising candidate for the development of high-resolution gas sensors for next-generation medical and healthcare applications.
Keywords: Acoustic gas sensing; Hybrid resonators; Fano resonance; Acoustically Induced Transparency; High-Q resonance; Scattering Matrix Method; Gas detection; Environmental monitoring; Resonant acoustic structures.

HARNESSING INDIGENOUS METAL-RESISTANT BACTERIA FOR PLANT GROWTH PROMOTION AND SUSTAINABLE REMEDIATION OF MINING-IMPACTED SOILS

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Abstract
Heavy metal contamination of mining-impacted soils poses a significant environmental and agricultural challenge because persistent metals can impair plant growth, disrupt soil microbial communities, and compromise ecosystem functioning. Plant growth–promoting rhizobacteria (PGPR)-assisted bioremediation offers an environmentally compatible and sustainable approach for reducing metal stress while enhancing plant performance. PGPR can immobilize, transform, or facilitate the removal of metals through mechanisms including biosorption, bioaccumulation, siderophore-mediated chelation, metal efflux, biotransformation, precipitation, biomineralization, and ACC deaminase activity. In addition, their ability to solubilize nutrients and produce phytohormones and other beneficial metabolites can improve plant establishment and resilience under metal stress. This study investigated indigenous Agrobacterium sp. and Microbacterium sp. strains isolated from mining-impacted soils for heavy metal tolerance, metal-resistance determinants, and plant-growth-promoting (PGP) traits. Isolates were evaluated for tolerance to selected heavy metals using agar dilution and broth microdilution assays. Metal-resistance genes were detected by polymerase chain reaction (PCR), while PGP potential was assessed qualitatively and quantitatively based on phosphate solubilization, indole-3-acetic acid (IAA), and siderophore production. Bacterial isolates were characterized phenotypically and identified by 16S rRNA gene sequencing. The Agrobacterium sp. and Microbacterium sp. isolates demonstrated substantial tolerance to the tested metals and carried metal-resistance genes, while also exhibiting phosphate-solubilizing activity and producing IAA and siderophores. The co-occurrence of metal resistance and multiple PGP traits suggests that these indigenous bacteria can contribute to metal stress alleviation, nutrient mobilization, and improved plant growth in contaminated soils. Overall, the findings identify Agrobacterium sp. and Microbacterium sp. as promising candidates for developing microbial inoculants for sustainable bioremediation and productivity enhancement of mining-impacted soils.

Keywords: Heavymetals; Mining-impacted soil; Plant growth-promoting rhizobacteria; Agrobacterium; Microbacterium; Metal resistance; Plant growth-promoting traits; Bioremediation; Indole-3-acetic acid; Siderophores.

MEDICINE AND SURGERY: HEALING NARRATIVES IN AFRICAN LITERATURE RESEARCH DOMAIN: MEDICINE, SURGERY, LANGUAGE & AFRICAN LITERATURE

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ABSTRACT
This research examines representations of medical knowledge, healing practices, and anatomical metaphors within African literary works. It investigates how African Literature reflects traditional and contemporary medical practices, including surgical metaphors and healing rituals. It highlights the role of narrative in transmitting medical knowledge and the symbolic significance of healing in cultural contexts. African Literature uses medical practices and anatomical metaphors to bridge traditional healing with modern medicine, framing the narrative itself as a powerful medium for processing personal, cultural, and political trauma. This intersection highlights several key thematic areas such as Traditional Healing versus Western Biomedicine, Anatomical Metaphors and Surgical Imagery as well as Narrative as a therapeutic ritual. Thus, through Wole Soyinka's *A Dance of the Forests* which explores physical mutilated bodies, spiritual illness, and the dark side of medical cum scientific authority in war-torn African societies and Ngũgĩ wa Thiong'o's *Wizard of the Crow* which uses satire, bodily ailments (such as unexplained swelling), and traditional wizardry cum healing to critique political dictatorship and cultural decay. Traditional healing and Western biomedicine represent two distinct paradigms of health, differing primarily in their philosophy, diagnostic methods, treatment approaches, and cultural contexts. While biomedicine relies on standardized scientific research to target physical symptoms, traditional healing views health through a holistic lens, integrating physical, spiritual, and social well-being.

Keywords: Medical Knowledge, African Literary Works, Healing Practices, Anatomical Metaphors**,** Traditional Wizardry**,**

A SEMI ANALYTICAL STUDY ON ENTROPY GENERATION OF EYRING-POWELL FLUID FLOW THROUGH A MICROCHANNEL

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ABSTRACT
In this work we communicates with the entropy generation analysis of Eyring Powell fluid flow through a microchannel in the thermal heat source coefficients. The dimensionless equations of the physical features along with the boundary conditions which are solved by using Homotopy analysis method. An expression of dimensionless velocity and dimensionless temperature are used to determination of the entropy generation number and bejan number explicitly. By using the analytical expression the thermal performances can be improved through the effects of magnetic field, viscous heating, joule heating and convective condition, futhermore it is explaining with graphically.

THE IMPACT OF PREOPERATIVE NURSING EDUCATION ON REDUCING ANXIETY AND IMPROVING POSTOPERATIVE RECOVERY IN SURGICAL PATIENTS

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ABSTRACT

Background
Preoperative nursing education plays a vital role in the perioperative care of surgical patients. Providing targeted information and psycho-emotional support directly influences the patient's physiological and psychological readiness, mitigating anxiety and facilitating recovery.

Objective
This study aims to evaluate the impact of structured preoperative nursing education on reducing situational anxiety and enhancing postoperative recovery outcomes among surgical patients.

Methodology
A cross-sectional quantitative study was conducted involving a sample of 69 surgical patients at the hospital surgical wards. Data were collected using a structured field questionnaire focusing on preoperative anxiety levels and postoperative recovery indicators. Statistical analysis was performed using IBM SPSS Statistics software.

Results
The findings revealed a statistically significant reduction in preoperative situational anxiety levels among patients who received structured nursing education compared to those receiving standard care ($p < 0.05$). Furthermore, preoperative instruction positively correlated with improved postoperative pain management, earlier mobilization, and enhanced overall recovery satisfaction.

Conclusions
Preoperative nursing education is an effective, non-pharmacological, and cost-efficient intervention that substantially reduces surgical anxiety and optimizes postoperative recovery. Implementing structured preoperative education protocols in routine perioperative nursing care is highly recommended.
Keywords: Preoperative education, Nursing care, Postoperative recovery, Situational anxiety, Surgical patients, SPSS analysis.

ANTIFUNGAL PROFILE OF FLAVONOID EXTRACTS OBTAINED FROM THE LEAVES THYMUS ALGERIENSIS BOISS. ET REUT

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ABSTRACT
Current research trends are steering policies toward measures that limit the use of synthetic drugs in favor of plant-based medicines.
To contribute to the valorization of Algerian flora, we conducted a study to identify the chemical composition of *Thymus algeriensis* (Lamiaceae family) leaves via phytochemical screening and to evaluate the antifungal activity of flavonoid-rich extracts (butanol, methanol, and ethanol) against two phytopathogenic strains: *Fusarium sp*. and *Rhizoctonia solani*.
Our work revealed the presence of several secondary metabolites, notably flavonoids, which were detected in significant quantities (78.96%).
Phytochemical screening results indicated that the aerial parts of this species are particularly rich in flavonoids.
All tested flavonoid-rich extracts proved effective against the mycelial growth of *Fusarium sp*., showing inhibition rates ranging from 88.58% to 96% and demonstrated fungicidal activity.
These extracts also exhibited remarkable fungicidal activity against *R. solani* hyphal growth, with inhibition rates between 85.42% and 89.29%.
Minimum Inhibitory Concentrations (MICs) were low, ranging from 0.062% to 0.125%, while Minimum Fungicidal Concentrations (MFCs) ranged from 0.062% to 1%.
In light of these results, the *in vitro* antifungal potential of the flavonoid-rich extract derived from *Thymus a*. leaves demonstrates significant inhibitory activity against both tested strains.
Furthermore, these extracts represent a promising source of natural antifungal agents.
Keywords: Thymus algeriensis, phytochemical screening, antifungal potential, flavonoid-rich extract

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NETWORK PHARMACOLOGY AND MULTI-OMICS PROFILING OF BERBERIS VULGARIS L. ALKALOIDS: MAPPING TARGET GENES ACROSS COMPLEX DISEASE NETWORKS

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ABSTRACT

Berberis vulgaris L. (common barberry) has a rich history in traditional medicine systems across Asia and Europe for treating metabolic, gastrointestinal, cardiovascular, and inflammatory conditions. While its primary alkaloid, berberine, is extensively documented, the holistic therapeutic efficacy of *B. vulgaris* relies on a complex mixture of isoquinoline and protoberberine alkaloids acting synergistically. In this study, we evaluate the comprehensive target bioactivity profiles and network pharmacology of *B. vulgaris* alkaloids, including berberine, berbamine, palmatine, oxyacanthine, jatrorrhizine, columbamine, dihydroberberine, oxyberberine, and juziphine. Gene-disease interactions have been evaluated through multi-omics interaction networks, to construct a bioactivity landscape of *B. vulgaris* alkaloids. Cross-target screening across major alkaloid target sets identified Nuclear factor NF-kappa-B p105 subunit (NF-κB1) as a universal core node, alongside highly conserved regulatory hubs such as TRIM24, HDAC8, Cathepsin D (CTSD), DUSP3, and APEX1. Subnetwork modeling revealed robust post-transcriptional microRNA regulatory circuits (including miR-17-5p, miR-27a-3p, and miR-128-3p) and key metabolic cross-talk involving ATP, ADP, and primary amino acids. DisGeNET association mapping linked these hub proteins directly to central nervous system pathologies (mood disorders, schizophrenia, major depressive disorder), metabolic conditions (type 2 diabetes mellitus), and cancers (adenocarcinoma, colonic neoplasms, ductal carcinoma). These findings validate a multi-target, multi-omics mechanism of action for *B. vulgaris*, establishing a theoretical framework for designing targeted phytotherapeutics against complex chronic diseases.

BEYOND VITAMIN D DEFICIENCY: CARDIOMETABOLIC PREDICTORS OF HYPERTENSIVE DISORDERS IN PREGNANCY

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ABSTRACT

Background: Hypertensive disorders of pregnancy (HDP), including gestational hypertension and preeclampsia, remain important causes of maternal and perinatal morbidity. Vitamin D has been increasingly investigated because of its potential involvement in placental development, endothelial function, immune regulation, and vascular homeostasis. However, reduced maternal vitamin D concentrations frequently coexist with obesity and other adverse metabolic and cardiovascular characteristics, raising the question of whether vitamin D deficiency represents an independent determinant of HDP or rather a component of a broader cardiometabolic risk profile. **Aim:** To evaluate maternal vitamin D status in pregnancies complicated by hypertensive disorders and to determine whether circulating 25-hydroxyvitamin D [25(OH)D] is independently associated with HDP after accounting for relevant maternal cardiometabolic factors.

Materials and Methods: This retrospective cohort study included 106 singleton pregnancies, comprising 90 normotensive women and 16 women with HDP, including gestational hypertension and preeclampsia. Maternal serum 25(OH)D concentrations, body mass index (BMI), systolic and diastolic blood pressure, serum uric acid, hematological parameters, and obstetric outcomes were evaluated. Vitamin D status was categorized according to clinically established thresholds. Logistic regression analyses were performed to identify factors associated with HDP and to assess whether vitamin D retained an independent association after multivariable adjustment.

Results: Women with HDP had significantly lower serum 25(OH)D concentrations than normotensive women (16.19 ± 6.43 vs. 20.12 ± 7.89 ng/mL, $p = 0.040$). They also had significantly higher BMI (33.11 ± 4.92 vs. 29.26 ± 5.01 kg/m², $p = 0.009$) and systolic blood pressure (130.94 ± 13.02 vs. 120.39 ± 10.14 mmHg, $p = 0.006$). Vitamin D deficiency was present in 68.8% of women with HDP compared with 53.3% of normotensive women, while no woman in the HDP group had sufficient vitamin D concentrations. Serum uric acid was also markedly higher in hypertensive pregnancies (4.58 ± 1.01 vs. 3.42 ± 0.89 mg/dL, $p < 0.001$). In univariate analysis, higher vitamin D concentrations were associated with lower odds of HDP (OR = 0.91, 95% CI 0.83–0.99, $p = 0.037$).

However, this association was attenuated after multivariable adjustment. Serum uric acid (adjusted OR = 3.01, p = 0.002) and systolic blood pressure (adjusted OR = 1.08, p = 0.032) remained independently associated with HDP.

Conclusions: Maternal vitamin D deficiency was more frequent and circulating 25(OH)D concentrations were significantly lower among pregnancies complicated by hypertensive disorders. However, vitamin D did not remain independently associated with HDP after adjustment for maternal cardiometabolic characteristics. In contrast, serum uric acid and systolic blood pressure emerged as independent correlates of hypertensive pregnancy. These findings support interpreting low vitamin D status within a broader cardiometabolic risk profile rather than as an isolated determinant of HDP and highlight the potential value of combining nutritional, metabolic, and hemodynamic markers in maternal risk assessment.

Keywords: vitamin D; hypertensive disorders of pregnancy; preeclampsia; gestational hypertension; cardiometabolic risk; uric acid; pregnancy.

DOSE-DEPENDENT EFFECTS OF IRON CHLORIDE ($FECL_3$) STRESS ON SEED GERMINATION, SEEDLING GROWTH, AND BIOMASS ACCUMULATION IN WHEAT (TRITICUM AESTIVUM L.)

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ABSTRACT
The purpose of the present study was to explain the adverse response of wheat (Triticum aestivum L.) to early seedling growth and physiological response of wheat under the stress of the FeCl3. 150 seeds were tested under five treatments T0 (control, distilled water), T1 (50 µM $FeCl_3$), T2 (100 µM $FeCl_3$), T3 (150 µM $FeCl_3$) and T4 (200 µM $FeCl_3$) and three replicates of 10 seeds each. On 7th day after sowing, the following data were obtained; root length, shoot length, fresh weight, dry weight and germination percentage. The results revealed that the maximum mean root length (9.73 cm) and shoot length (9.67 cm) was observed in the control group whereas the minimum root length (5.73 cm) and shoot length (6.27 cm) was observed in T3 and T4 respectively.The fresh weight range (0.412g (T0) to 0.228g (T4)) and dry weight range (0.185g (T0) to 0.103g (T4)) showed that biomass was significantly reduced with high concentration of FeCl3.The highest percentage of germination was in the control (96 %), followed by decreasing rate in T4 (dose dependent inhibition) 68 %.The treatments were significantly different ($p<0.05$) by ANOVA statistical analysis. The results showed that there was a negative correlation between wheat growth parameters with $FeCl_3$ concentration, which is in line with the finding in literature that $FeCl_3$ induced oxidative stress that led to chlorophyll degradation. The findings highlight the double function of Fe as an essential nutrient and phytotoxic element at high concentrations. The study provides information in the management of iron contamination in the soil as well as in the production of wheat under heavy metal stresses.

Keywords: Wheat, Iron Chloride Stress, Root Length, Shoot Length, Biomass, Germination, Photosynthetic Pigments, Heavy Metals.

BEYOND HOT FLUSHES: THE MULTIDIMENSIONAL BURDEN OF MENOPAUSAL SYMPTOMS AND IMPLICATIONS FOR WOMEN'S HEALTHCARE

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ABSTRACT

Background: Menopause is a complex biological transition characterized by a broad spectrum of vasomotor, psychological, somatic, and urogenital manifestations. Although hot flushes are commonly regarded as the hallmark of menopause, other symptoms may substantially affect daily functioning, quality of life, and healthcare needs. Their simultaneous occurrence highlights the importance of moving beyond isolated symptom assessment toward a comprehensive, patient-centered approach to menopause care.

Aim: To characterize the multidimensional burden of menopausal symptoms among women attending gynecological care and to identify the symptom domains that should receive greater attention in routine clinical assessment.

Materials and Methods: This cross-sectional analysis included a randomly selected sample of 120 menopausal women with complete questionnaire data. Eleven symptoms covering somatic, psychological, and urogenital domains were evaluated: hot flushes and sweating, cardiac complaints, sleep disturbances, depressive mood, irritability, anxiety, physical and mental exhaustion, sexual problems, bladder symptoms, vaginal dryness, and musculoskeletal complaints. Symptom severity was graded, and an overall symptom score was calculated to estimate cumulative symptom burden.

Results: The mean age of participants was 49.82 ± 7.78 years, and 75.0% were from urban areas. Hot flushes and sweating were reported by 89.2% of women, with 59.2% experiencing moderate-to-severe vasomotor symptoms. Importantly, the symptom burden extended considerably beyond vasomotor manifestations.

Sleep disturbances affected 81.7% of participants, physical and mental exhaustion 71.7%, and musculoskeletal complaints 70.0%. Urogenital symptoms were also highly prevalent, including vaginal dryness in 65.8%, sexual problems in 62.5%, and bladder symptoms in 60.0%. Psychological manifestations included irritability (50.8%), depressive mood (44.2%), and anxiety (42.5%). The mean overall symptom score was 11.17 ± 6.00, indicating a substantial cumulative and multidimensional symptom burden.

Conclusions: Menopausal symptom burden is highly prevalent and extends far beyond the traditionally emphasized vasomotor manifestations. Sleep disturbances, fatigue, musculoskeletal complaints, and urogenital symptoms emerged as major components of the menopausal experience and should be actively investigated during routine healthcare encounters. Systematic incorporation of patient-reported symptom assessment may facilitate earlier recognition of clinically relevant problems, improve patient–clinician communication, and support more individualized and multidisciplinary menopause care.

Keywords: menopause; menopausal symptoms; symptom burden; women's health; patient-reported outcomes; quality of life; personalized care.

MATERNAL ANEMIA AND INTERLEUKIN-6 PROFILES IN COVID-19 PREGNANCIES COMPLICATED BY HYPERTENSIVE DISORDERS

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Background: Background: Pregnancy complicated by COVID-19 may be associated with an enhanced systemic inflammatory response, while hypertensive disorders of pregnancy are characterized by endothelial dysfunction and altered inflammatory pathways. Anemia represents an additional maternal condition that may impair oxygen delivery and potentially aggravate the clinical burden of high-risk pregnancies. Interleukin-6 (IL-6), a major mediator of systemic inflammation, has also been implicated in alterations of iron metabolism and erythropoiesis. However, the relationship between maternal inflammatory activity and hemoglobin concentrations in pregnancies simultaneously complicated by COVID-19 and hypertensive disorders remains insufficiently characterized.

Aim: To evaluate maternal hemoglobin and IL-6 profiles in pregnant women with COVID-19 and hypertensive disorders of pregnancy and to investigate the relationship between systemic inflammatory activity and maternal anemia.

Materials and Methods: This observational study included 52 pregnant women diagnosed with COVID-19 and hypertensive disorders of pregnancy, including gestational hypertension and preeclampsia. Serum IL-6 concentrations and maternal hemoglobin levels were assessed in all participants. Anemia was defined as a hemoglobin concentration <11 g/dL. Correlation analyses were performed to investigate the relationship between IL-6 and hemoglobin levels, and IL-6 concentrations were compared according to maternal anemia status.

Results: Mean maternal hemoglobin concentration was 10.63 ± 1.50 g/dL, ranging from 7.84 to 13.97 g/dL. Anemia was identified in 32 of the 52 participants (61.5%), demonstrating a substantial anemia burden in this high-risk population.

IL-6 concentrations showed considerable interindividual variability, with a mean value of 35.44 ± 123.50 pg/mL and a median of 6.30 pg/mL. Spearman correlation analysis showed a weak inverse relationship between IL-6 and hemoglobin ($\rho = -0.094$, $p = 0.508$). Pearson analysis also indicated an inverse trend ($r = -0.232$, $p = 0.098$), although statistical significance was not reached. Women with anemia had a markedly higher mean IL-6 concentration than women without anemia (48.49 vs. 14.58 pg/mL); however, this difference was not statistically significant, in the context of the highly skewed IL-6 distribution and substantial interindividual variability.

Conclusions: Anemia was highly prevalent among pregnant women with COVID-19 and hypertensive disorders of pregnancy, affecting more than 60% of the study population. Although IL-6 concentrations tended to be higher in women with anemia and both correlation analyses suggested an inverse relationship between inflammatory activity and maternal hemoglobin, these associations did not reach statistical significance. These findings suggest that anemia represents an important comorbidity in pregnancies characterized by concomitant infectious and hypertensive complications, while the potential contribution of systemic inflammation to maternal anemia requires confirmation in larger cohorts incorporating specific biomarkers of iron metabolism and inflammatory status.

Keywords: interleukin-6; maternal anemia; hemoglobin; COVID-19; pregnancy; hypertensive disorders of pregnancy; preeclampsia; inflammation.

MATERNAL ZINC STATUS AND HEMATOLOGICAL HEALTH DURING PREGNANCY: PRELIMINARY INSIGHTS INTO MICRONUTRIENT VULNERABILITY

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ABSTRACT

Background: Adequate maternal micronutrient status is essential for physiological adaptation to pregnancy and normal fetal development. Zinc plays a central role in cellular proliferation, protein synthesis, immune regulation, and fetal growth, while pregnancy itself increases maternal micronutrient requirements. Although iron deficiency is routinely considered when evaluating maternal anemia, other micronutrient deficiencies may coexist and contribute to a broader pattern of nutritional vulnerability. The relationship between maternal zinc status and hematological parameters during pregnancy therefore deserves further investigation.

Aim: To evaluate maternal zinc status during pregnancy and explore its relationship with hemoglobin concentration, anemia, gestational characteristics, and other available markers of maternal micronutrient status.

Materials and Methods: This observational study was designed to include 100 pregnant women, with serum zinc concentrations assessed predominantly during the second trimester. Participants were categorized according to zinc status into groups with decreased or adequate serum zinc concentrations.

Maternal age, gestational age, hemoglobin concentration, anemia status, and available micronutrient parameters, including vitamin D, were considered. Correlation and comparative analyses were designed to investigate associations between maternal zinc status and hematological, nutritional, and gestational characteristics.

Results: Preliminary assessment demonstrated considerable interindividual variability in maternal serum zinc concentrations, indicating heterogeneous micronutrient status within the study population. Reduced zinc concentrations were identified among a proportion of the evaluated pregnant women and appeared to coexist with lower hemoglobin levels in some cases. These preliminary observations suggest a possible overlap between impaired zinc status and maternal hematological vulnerability. Analysis of the complete 100-patient cohort will establish the prevalence of reduced zinc status and quantify its relationships with hemoglobin concentration, anemia, gestational age, and other available micronutrient parameters.

Conclusions: Preliminary findings indicate that inadequate zinc status may coexist with impaired hematological parameters during pregnancy, supporting a more comprehensive approach to maternal nutritional assessment beyond iron status alone. Evaluation of zinc alongside hemoglobin and other micronutrient markers may help identify pregnant women with broader nutritional vulnerability. Completion of the cohort and subsequent quantitative analyses will be necessary to determine the strength and clinical relevance of these associations and their potential implications for individualized nutritional management during pregnancy.

Keywords: zinc; pregnancy; micronutrient status; anemia; hemoglobin; maternal nutrition; nutritional vulnerability.

ENHANCED MECHANICAL AND THERMAL PROPERTIES OF ALKALI-TREATED COIR FIBERS INCORPORATED WITH MURRAYA KOENIGII: A COMPARATIVE STUDY OF MONO-LAYER AND TRI-LAYER BIOCOMPOSITES

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ABSTRACT
This study examined the surface morphology and thermal behavior of the coir fibers incorporated with Murraya koenigii before and after alkaline treatment. The mechanical properties of biocomposites reinforced by the untreated fibers, treated fibers, mono-layer and tri-layer treated fibers incorporated with Murraya koenigii were systematically investigated. The experimental results showed significant enhancements in tensile strength, flexural strength, hardness, and impact resistance of the biocomposites reinforced by treated fibers. Notably, the alkaline treatment has produced a rougher surface on coir fibers, promoting improved mechanical interlocking between the fibers and the polyethene matrix. These effects become more significant when Murraya koenigii particles are incorporated into the fibers. It was found that the tri-layer treated fibers incorporated with Murraya koenigii biocomposites showed higher tensile and flexural strength, superior hardness, and impact strength when compared to the mono-layer reinforcement biocomposites. At higher temperatures, the treated fibers showed better thermal stability than the untreated fibers and polyethene. Incorporating Murraya koenigii particles increased the thermal resistance of the treated fibers, revealing the potential of this green synthesis approach for the development of thermally stable natural fiber composites.
Keywords: Coconut coir fibers, Murraya koenigii, surface morphology, thermal behavior, mechanical properties

EVALUATION OF SALT TOLERANCE IN ANNUAL RYEGRASS (LOLIUM MULTIFLORUM L.) CULTIVARS DURING GERMINATION AND SEEDLING DEVELOPMENT

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ÖZET
Bu çalışmada, artan sodyum klorür (NaCl) dozlarının (0, 30, 60, 90 ve 120 mM) üç tek yıllık çim çeşidinde (Elif, Fırtına ve Mir) çimlenme ve erken fide gelişimi üzerine etkileri belirlenmiştir. Deneme, tesadüf parselleri deneme deseninde üç tekrarlı olarak petri kaplarında yürütülmüştür. Çimlenme oranı, radikula (kök) uzunluğu, plumula (sürgün) uzunluğu ile radikula ve plumula yaş ve kuru ağırlıkları ölçülmüş; radikula/plumula oranı, fide vigor indeksi (SVI-I), fide su içeriği ile radikula ve plumula stres tolerans indeksleri (RSTI ve PSTI) ve nispi çimlenme değerleri hesaplanmıştır. Veriler iki yönlü varyans analizi ile değerlendirilmiş, ortalamalar Tukey testi ile gruplandırılmıştır. Artan tuz konsantrasyonu çimlenme oranını, radikula ve plumula uzunluğunu, fide yaş ve kuru ağırlıklarını ve vigor indeksini önemli düzeyde ($p<0,001$) azaltmıştır. En yüksek dozda (120 mM) çimlenme oranı kontrole kıyasla yaklaşık yarıya inmiş, vigor indeksi büyük ölçüde gerilemiştir. Buna karşın fide su içeriği tuz dozundan ve çeşitten önemli düzeyde etkilenmemiş, radikula/plumula oranı ise tuzla artarak sürgün gelişiminin kökten daha fazla baskılandığını göstermiştir. Tolerans indekslerine göre Elif ve Mir çeşitleri tuza nispeten daha toleranslı, Fırtına çeşidi ise en hassas çeşit olarak belirlenmiştir.
Anahtar Kelimeler: Çim, tuz stresi, çimlenme, radikula, plumula, vigor indeksi, tolerans indeksi.

Abstract
In this study, the effects of increasing sodium chloride (NaCl) doses (0, 30, 60, 90 and 120 mM) on germination and early seedling growth of three annual ryegrass (*Lolium multiflorum* Lam.) cultivars (Elif, Fırtına and Mir) were determined. The experiment was carried out in Petri dishes with three replications according to a completely randomized design. Germination rate, radicle and plumule lengths, and fresh and dry weights of radicle and plumule were measured; radicle/plumule ratio, seedling vigor index (SVI-I), seedling water content, radicle and plumule stress tolerance indices (RSTI and PSTI) and relative germination were calculated. Data were analyzed by two-way analysis of variance and means were grouped by Tukey's test. Increasing salt concentration significantly ($p<0.001$) reduced germination rate, radicle and plumule lengths, fresh and dry weights and vigor index. At the highest dose (120 mM), germination was reduced to about half of the control and the vigor index declined markedly. Seedling water content, however, was not significantly affected by salt dose or cultivar, whereas the radicle/plumule ratio increased with salinity, indicating that shoot growth was suppressed more than root growth. According to the tolerance indices, Elif and Mir were relatively more salt-tolerant, while Fırtına was the most sensitive cultivar.
Keywords: Annual ryegrass, salt stress, germination, radicle, plumule, vigor index, tolerance index.

1. Introduction
Soil and water salinity is one of the most widespread abiotic stress factors limiting crop production worldwide, and it has become an increasingly serious problem, particularly in arid and semi-arid regions, owing to inadequate drainage and irrigation with low-quality water. The adverse effect of salinity on plants is explained by a two-phase process: an osmotic phase, which arises from the decrease in osmotic potential in the root zone and rapidly restricts water uptake, and a slower ionic phase, which develops as sodium and chloride ions accumulate in the tissues (Munns and Tester, 2008). Together, these two mechanisms disrupt cell division, water relations and enzyme activities, thereby suppressing growth at all developmental stages from germination to maturity (Parida and Das, 2005).
Although all developmental stages are affected by salinity, germination and the early seedling stage are regarded as the most salt-sensitive period. During this stage, salt stress both hampers water uptake by the seed through its osmotic effect and impairs embryo development through ion toxicity, thereby reducing the germination rate and decreasing radicle (root) and plumule (shoot) length as well as seedling weight (Parida and Das, 2005).

Because success in germination and seedling emergence directly determines the uniform and rapid establishment of the plant stand, knowledge of performance during this stage under saline conditions is of great importance for the selection of suitable species and cultivars.

Annual ryegrass (*Lolium multiflorum* Lam.) is a cool-season grass that germinates rapidly and can form a dense green cover within a short time. Owing to these characteristics, it is widely used for the rapid establishment of turf areas, for overseeding existing turf, and in turf seed mixtures; it is also valued as an important forage crop with high yield and nutritional quality. Because turf and pasture areas are increasingly irrigated with treated wastewater, recycled water or low-quality water with a high salt content as a result of growing water scarcity, the germination performance of this species under saline conditions directly affects establishment success (Meyer et al., 2017). In cool-season turfgrasses, the response to salinity varies markedly not only among species but also among cultivars within the same species; indeed, marked physiological and molecular differences have been demonstrated between salt-sensitive and salt-tolerant genotypes of annual ryegrass (Feng et al., 2022). Therefore, comparative studies conducted at the cultivar level enable the selection of the appropriate cultivar for the establishment of saline areas (Ali Harivandi et al., 1992; Kozłowska et al., 2021).

The effects of salt stress during the germination stage in turfgrasses have been addressed in various studies. In studies on tall fescue (*Festuca arundinacea*), increasing salt concentration was reported to adversely affect shoot and root length, fresh weight, vigor index and salt tolerance index, whereas the germination percentage was maintained up to a certain threshold and declined at higher doses (Öztürk et al., 2018; Türk and Alagöz, 2020). As in these studies, the vigor index—which jointly reflects germination rate and seedling length—and the tolerance indices calculated relative to the control are criteria commonly used for the comparative evaluation of the salt response of cultivars (Abdul-Baki and Anderson, 1973).

By contrast, the salt response during germination of many annual ryegrass cultivars used in Türkiye has not yet been comparatively demonstrated. The aim of this study was to determine the germination and early seedling growth characteristics of three annual ryegrass (*Lolium multiflorum* Lam.) cultivars (Elif, Fırtına and Mir) under increasing NaCl concentrations (0, 30, 60, 90 and 120 mM), and to compare and rank the cultivars in terms of salt tolerance using germination rate, radicle and plumule length, fresh and dry weight, vigor index, and the radicle/plumule and relative germination tolerance indices.

2. Materials and Methods

The plant material of the study consisted of seeds of three cultivars (Elif, Fırtına and Mir) of annual ryegrass, *Lolium multiflorum* Lam., a cool-season grass. Uniform, plump and undamaged seeds were used. The experiment was established in a total of 45 Petri dishes according to a completely randomized design as three cultivars × five salt doses × three replications. Prior to germination, the seeds were surface-sterilized; for this purpose, the seeds were kept in jars containing 2% sodium hypochlorite (commercial bleach) solution on a shaker for 10 min and then rinsed five times with sterile distilled water to remove the chemical residue from their surface (Bilgili et al., 2011).

The sterilized seeds were sown, under a sterile cabinet, into sterile Petri dishes 11 cm in diameter and 10 mm in height lined with double-layered coarse filter paper, at 50 seeds per dish, and the dishes were sealed with parafilm to prevent air exchange. The treatment solutions were prepared by dissolving NaCl in distilled water to concentrations of 0 (control), 30, 60, 90 and 120 mM; 10 mL of the respective solution was added to each dish, and only distilled water was added to the control group. The dishes were kept in a germination cabinet set at 21 °C under dark conditions for 21 days. Seeds with a radicle longer than 2 mm were considered germinated.

At the end of the 21-day germination period, germinated seeds were counted and the germination rate was calculated using Equation (1). Radicle (root) and plumule (shoot) lengths were measured in millimetres on 25 randomly selected seedlings per dish; seedling length was obtained using Equation (2) and the radicle/plumule (R/S) ratio using Equation (3). The fresh weights of the radicle and plumule of the same seedlings were determined, after which the samples were oven-dried at 70 °C for 48 h to obtain their dry weights, and seedling water content was calculated using Equation (4). The seedling vigor index was calculated using Equation (5) (Abdul-Baki and Anderson, 1973); the salt tolerance criteria were calculated relative to each cultivar's own control mean as the radicle stress tolerance index (Equation 6), the plumule stress tolerance index (Equation 7) and relative germination (Equation 8).

Petri-dish germination and measurement procedures were carried out in accordance with the methods followed in similar studies (Öztürk et al., 2018; Türk and Alagöz, 2020).

GR (%) = (number of germinated seeds / number of sown seeds) × 100 (1)

Seedling length (mm) = Radicle length + Plumule length (2)

R/S = Radicle length / Plumule length (3)

Water content (%) = [(Fresh weight − Dry weight) / Fresh weight] × 100 (4)

SVI-I = GR (%) × Seedling length (cm) (5)

RSTI (%) = (Treatment radicle length / Control radicle length) × 100 (6)

PSTI (%) = (Treatment plumule length / Control plumule length) × 100 (7)

Relative germination (%) = (Treatment GR / Control GR) × 100 (8)

The data were evaluated by two-way analysis of variance (ANOVA) including the main effects of cultivar and salt dose and the cultivar × dose interaction, using the SPSS software package. Means were grouped according to Tukey's multiple comparison test ($p<0.05$); means denoted by the same letter in the tables were considered not significantly different.

3. Results

The results of the two-way analysis of variance for the traits examined are presented in Table 4. For all traits except seedling water content, the main effects of cultivar and salt dose were significant at the 0.1% level ($p<0.001$), the cultivar × dose interaction was also significant for almost all traits except radicle length. The effect of salt dose was particularly pronounced for germination rate, vigor index and plumule length. Coefficients of variation ranged from 2.0% to 15.8%, supporting the reliability of the data.

Under control conditions, the germination rate ranged from 90.4% (Mir) to 95.7% (Fırtına) depending on cultivar (Table 1). At the low dose (30 mM), germination remained statistically in the same group as the control (Elif 91.0%; Fırtına 92.4%; Mir 89.0%), and a marked decrease began from 60 mM onwards. At the highest dose (120 mM), germination fell to 49.7% in Elif, 52.2% in Fırtına and 44.5% in Mir; that is, it decreased by approximately 46–51% relative to the control, dropping to about half of the control in all cultivars.

Table 1. Effect of salt doses on radicle and plumule length, seedling length, R/S ratio, germination rate and vigor index in the ryegrass cultivars

Cultivar	Dose (mM)	Radicle length (mm)	Plumule length (mm)	Seedling length (mm)	R/S	Germination (%)	Vigor (SVI-I)
Elif	0	62.6±0.9a	53.2±2.0a	115.9±2.1a	1.18±0.05c	92.7±1.8a	1074±14a
Elif	30	58.5±3.6a	48.2±2.3b	106.7±4.5a	1.21±0.09c	91.0±1.9a	971±61a
Elif	60	56.8±3.2a	41.4±0.8c	98.2±3.4b	1.37±0.08b	84.7±1.5b	832±41b
Elif	90	50.4±2.4b	39.1±2.4c	89.5±4.8b	1.29±0.02c	72.9±3.7c	651±20c
Elif	120	46.2±2.0b	23.5±0.6e	69.8±2.3c	1.96±0.08a	49.7±5.0d	347±33d
Fırtına	0	55.5±2.8a	35.1±2.9d	90.6±4.8b	1.59±0.12b	95.7±2.3a	866±40b
Fırtına	30	54.6±4.5a	33.6±2.4d	88.2±3.9b	1.63±0.21b	92.4±0.9a	815±28b
Fırtına	60	37.8±1.8c	17.7±0.7f	55.4±1.9d	2.14±0.15a	82.2±2.2b	455±26d
Fırtına	90	32.9±1.3c	16.2±0.8f	49.1±1.7d	2.04±0.11a	66.4±3.4c	326±20e
Fırtına	120	29.8±1.2c	14.2±1.3f	44.0±2.3d	2.10±0.17a	52.2±0.7d	230±9e
Mir	0	58.3±6.4a	55.6±2.3a	113.9±8.5a	1.05±0.08c	90.4±0.7a	1029±69a
Mir	30	53.3±5.7a	55.2±0.9a	108.5±6.5a	0.96±0.09c	89.0±0.5a	965±53a
Mir	60	49.0±2.6b	50.2±1.6b	99.2±3.3b	0.98±0.05c	79.0±1.0b	784±24b
Mir	90	46.1±3.2b	47.0±1.1b	93.1±2.4b	0.98±0.09c	68.5±3.0c	638±26c
Mir	120	38.7±4.6c	32.8±0.7d	71.5±5.2c	1.18±0.12c	44.5±4.6d	319±51e

Means followed by the same letter within a column are not significantly different.

Radicle length was 55.5–62.6 mm in the control and decreased to 29.8–46.2 mm at 120 mM; the greatest reduction was observed in Fırtına, whereas Elif was the least affected cultivar. Plumule length was more strongly affected by salt than radicle length: values of 35.1–55.6 mm in the control decreased to 14.2–32.8 mm at 120 mM.

The reduction in plumule length was 56% in Elif, 60% in Fırtına and 41% in Mir. Fırtına produced the shortest plumule values (14.2–17.7 mm) at 60 mM and above, clearly separating from the other two cultivars for this trait.

The changes in radicle and plumule length, germination rate and vigor index in response to salt dose are shown in Figure 1. For all four traits, values decreased regularly with increasing NaCl concentration and reached their lowest levels at the highest dose (120 mM); while Elif and Mir maintained higher values, Fırtına showed the most rapid decline in all parameters (Figure 1).

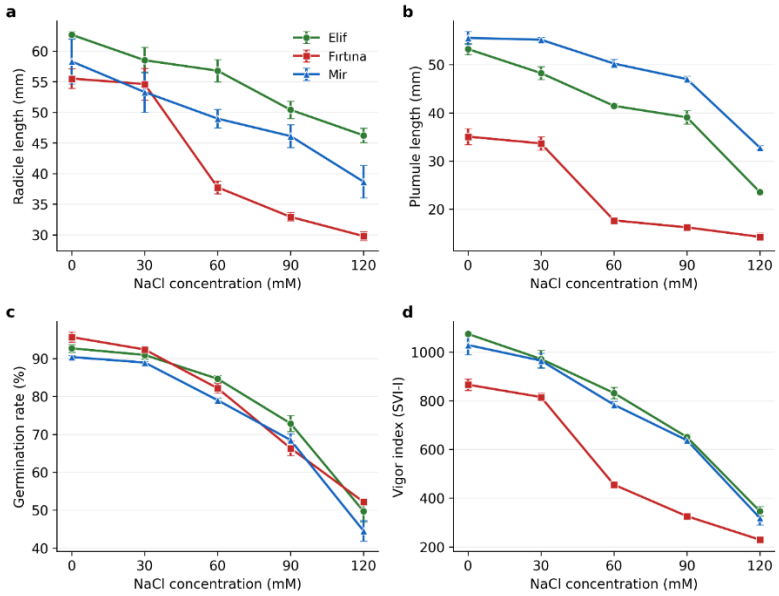


Figure 1. Effect of increasing NaCl doses on radicle length (a), plumule length (b), germination rate (c) and vigor index (d) in the three ryegrass cultivars

The R/S ratio generally increased with increasing salt dose (Table 1). It increased from 1.18 (control) to 1.96 (120 mM) in Elif and from 1.59 to 2.10 in Fırtına, whereas it remained relatively constant (1.05–1.18) in Mir. This increase indicates that, under salt stress, plumule growth was suppressed more than radicle growth.

Table 2. Effect of salt doses on radicle and plumule fresh and dry weights and seedling water content.

Cultivar	Salt dose (mM)	Radicle fresh (mg)	Plumule fresh (mg)	Radicle dry (mg)	Plumule dry (mg)	Water content (%)
Elif	0	3.59±0.54b	18.03±1.02a	0.475±0.079a	3.212±0.645a	83.0±2.8a
Elif	30	3.57±0.30b	15.92±1.38a	0.457±0.091a	2.631±0.492a	84.2±1.4a
Elif	60	3.17±0.04b	14.01±1.11b	0.362±0.044b	2.536±0.280a	83.1±1.4a
Elif	90	1.19±0.05d	9.30±0.92c	0.157±0.028c	1.587±0.314b	83.4±2.0a
Elif	120	0.89±0.04e	11.63±0.91c	0.119±0.009c	2.029±0.301b	82.9±1.6a
Fırtına	0	4.49±0.23a	10.11±0.80c	0.580±0.078a	2.045±0.180b	82.0±1.1a
Fırtına	30	3.12±0.22b	9.95±0.78c	0.270±0.023b	1.772±0.140b	84.4±1.3a
Fırtına	60	1.84±0.19d	7.62±1.31d	0.198±0.026c	1.287±0.233b	84.3±0.3a
Fırtına	90	1.41±0.20d	6.13±0.35d	0.170±0.011c	1.135±0.141b	82.7±2.0a
Fırtına	120	0.84±0.09e	5.81±0.77d	0.099±0.005c	1.104±0.159b	81.9±1.2a
Mir	0	4.13±0.31a	16.98±0.81a	0.577±0.049a	3.381±0.244a	81.3±0.4a
Mir	30	3.85±0.31a	16.22±0.63a	0.434±0.034a	2.912±0.594a	83.4±2.6a
Mir	60	2.77±0.23c	15.62±0.73a	0.389±0.035b	2.771±0.207a	82.8±0.4a
Mir	90	2.58±0.23c	14.32±0.67b	0.318±0.051b	2.628±0.475a	82.6±2.2a
Mir	120	2.63±0.24c	10.35±0.48c	0.327±0.058b	1.739±0.168b	84.1±1.8a

Means followed by the same letter within a column are not significantly different.

The fresh and dry weights of the radicle and plumule decreased with increasing salt dose (Table 2). For example, radicle fresh weight in Elif decreased from 3.59 mg (control) to 0.89 mg (120 mM) and radicle dry weight from 0.475 mg to 0.119 mg. In contrast, seedling water content remained at approximately 81–84% across all cultivars and doses, and none of the cultivar, dose or interaction effects were significant in the analysis of variance. This result shows that, under salt stress, the relative water content of the tissue was maintained while the absolute dry and fresh biomass accumulated per seedling decreased.

Table 3. Radicle (RSTI) and plumule (PSTI) stress tolerance indices and relative germination values of the ryegrass cultivars by salt dose (control = 100%).

Cultivar	Salt dose (mM)	RSTI (%)	PSTI (%)	Relative germination (%)
Elif	30	93.4±5.8a	90.6±4.3a	98.1±2.0a
Elif	60	90.6±5.0a	77.9±1.5b	91.3±1.7b
Elif	90	80.5±3.9b	73.4±4.5b	78.6±4.0c
Elif	120	73.8±3.2b	44.2±1.0d	53.6±5.4e
Fırtına	30	98.4±8.1a	96.0±6.9a	96.6±0.9a
Fırtına	60	68.0±3.3b	50.4±2.1c	85.9±2.3b
Fırtına	90	59.3±2.3c	46.2±2.4d	69.4±3.5d
Fırtına	120	53.7±2.2c	40.6±3.7d	54.5±0.8e
Mir	30	91.4±9.8a	99.3±1.6a	98.4±0.6a
Mir	60	84.0±4.5a	90.4±2.8a	87.4±1.1b
Mir	90	79.1±5.6b	84.6±2.0b	75.8±3.3c
Mir	120	66.3±7.8b	59.0±1.3c	49.3±5.1e

Means followed by the same letter within a column are not significantly different.

The seedling vigor index (SVI-I) ranged from 865.9 (Fırtına) to 1074.1 (Elif) in the control and declined to 229.6–346.7 at 120 mM, a reduction of 68–73% in all cultivars (Table 1). The tolerance indices calculated relative to the control summarize the differences among cultivars (Table 3): at 120 mM, the radicle stress tolerance index (RSTI) was 73.8% in Elif, 66.3% in Mir and 53.7% in Fırtına, while the plumule stress tolerance index (PSTI) was 59.0% in Mir, 44.2% in Elif and 40.6% in Fırtına. Relative germination fell to 49–55% in all cultivars at 120 mM. Considering the vigor index and tolerance indices together, Elif and Mir stood out as relatively more salt-tolerant, whereas Fırtına was the most sensitive cultivar.

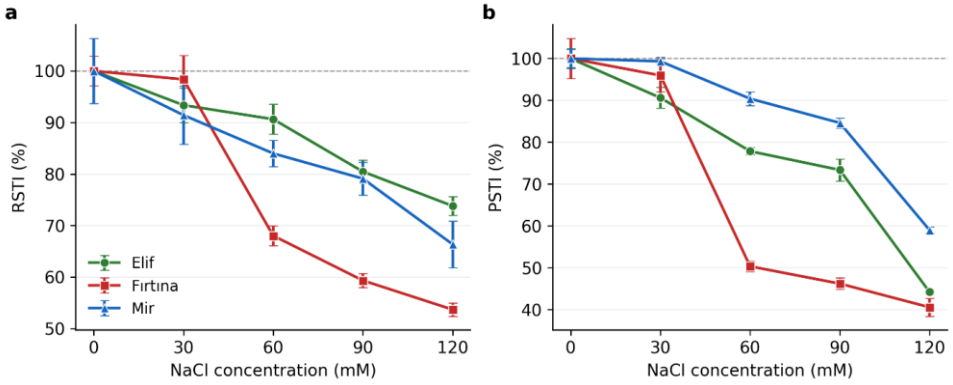


Figure 2. Effect of increasing NaCl doses on the radicle stress tolerance index (RSTI, a) and plumule stress tolerance index (PSTI, b) in the three ryegrass cultivars.

The changes in the radicle and plumule stress tolerance indices in response to salt dose are shown in Figure 2. Both indices declined regularly with increasing NaCl concentration; while Elif and Mir maintained higher RSTI values and Mir in particular maintained higher PSTI values, Fırtına showed the lowest tolerance values at all doses (Figure 2).

Table 4. F values and significance levels of the analysis of variance for the examined traits.

Trait	Cultivar (F)	Dose (F)	Cultivar×Dose (F)	CV (%)
Radicle length	51.4***	54.4***	3.6**	7.1
Plumule length	847.5***	299.3***	14.7***	4.5
Seedling length	267.1***	164.4***	6.7***	4.9
Radicle/Plumule	234.3***	28.7***	8.2***	7.7
Germination rate	10.0***	432.6***	2.3*	3.4
Vigor index (SVI-I)	170.3***	485.9***	8.1***	5.6
Radicle fresh weight	50.9***	185.5***	16.7***	9.3
Plumule fresh weight	257.0***	72.2***	7.5***	7.3
Radicle dry weight	34.5***	80.2***	6.7***	14.8
Plumule dry weight	51.0***	19.3***	1.9ns	15.8
Seedling water content	0.3ns	1.6ns	0.7ns	2.0
RSTI	15.7***	55.4***	4.5**	7.2
PSTI	98.7***	265.8***	20.7***	5.1
Relative germination	4.6*	430.3***	2.5*	3.4

****p<0.001; **p<0.01; *p<0.05; ns: not significant; CV: coefficient of variation.*

4. Discussion

In this study, increasing NaCl concentration significantly reduced germination rate, radicle and plumule length, seedling fresh and dry weights and vigor index in the three *Lolium multiflorum* cultivars. This general trend is consistent with the mechanism whereby salinity suppresses plant growth first through the low osmotic potential in the root zone and then through the toxic effect of ions accumulating in the tissues (Munns and Tester, 2008; Parida and Das, 2005). A recent study conducted with four cultivars of the same species (*Lolium multiflorum*) likewise reported that increasing salinity markedly reduced shoot and root length and seedling fresh and dry weights, and that the cultivar × salinity interaction was significant for most of the traits examined; our findings largely agree with these results. Similarly, studies on tall fescue (*Festuca arundinacea*) reported that increasing salt concentration adversely affected shoot and root length, fresh weight and vigor index (Öztürk et al., 2018; Türk and Alagöz, 2020).

It is noteworthy that at the low dose (30 mM) germination remained at the same level as the control and that a marked decline occurred only at higher doses. Öztürk et al. (2018) similarly reported that in tall fescue the germination percentage was maintained up to a certain threshold but progressively decreased once the threshold was exceeded. Low salinity levels have been reported not generally to limit—and in some cases to slightly stimulate germination and early seedling growth in cool-season turfgrasses (Kozłowska et al., 2021); the limited effect of the 30 mM dose in our study is consistent with this finding. The increase in the R/S ratio with salinity indicates that plumule growth was suppressed more than radicle growth. This can be explained by the mechanism emphasizing that the osmotic phase of salinity primarily restricts the growth of young shoots and leaves (Munns and Tester, 2008). The maintenance of seedling water content at approximately 83%, independent of salt dose and cultivar, suggests that the tissue sustained its water status through osmotic adjustment while absolute biomass accumulation decreased (Parida and Das, 2005). The marked decline in the vigor index at high doses is a composite reflection of the simultaneous reduction in germination and seedling length; the vigor index is therefore used as an effective criterion for evaluating the salt response (Abdul-Baki and Anderson, 1973).

The differences among cultivars revealed that salt tolerance also varies considerably within the species. While Elif and Mir gave higher values for the tolerance indices and the vigor index, Fırtına was the most sensitive cultivar, with the lowest values particularly for plumule length and vigor index. Marked physiological and molecular differences between salt-sensitive and salt-tolerant genotypes of *Lolium multiflorum* have been demonstrated previously (Feng et al., 2022). It is emphasized that the salt response of turfgrasses varies by species and cultivar, and that tolerant cultivars should therefore be selected for saline areas (Ali Harivandi et al., 1992; Kozłowska et al., 2021).

The present results are consistent with findings supporting the importance of evaluating salt tolerance at the cultivar level in breeding and establishment studies (Meyer et al., 2017). Accordingly, the cultivars Elif and Mir may be recommended for turf establishment in areas where salinity is a problem.

5. Conclusions

Increasing NaCl concentration significantly reduced germination rate, radicle and plumule length, seedling fresh and dry weights and vigor index in all three ryegrass cultivars, with the most marked decline occurring at the 90–120 mM doses. The fact that seedling water content was not affected by salt dose indicates that the tissue maintained its relative water content. Considering the tolerance indices and vigor index together, Elif and Mir stood out as relatively more salt-tolerant, whereas Fırtına was the most sensitive cultivar. These results indicate that the cultivars Elif and Mir may be preferred for turf establishment in areas where salinity is a problem.

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"2. ISPEC ULUSLARARASI BİLİMSEL İŞ BİRLİĞİ VE DİSİPLİNLERARASI ARAŞTIRMALAR KONGRESİ"

SEPTEMBER 02-07, 2026 / BUDAPEST, HUNGARY

REF: AKADEMİK TEŞVİK

İLGİLİ MAKAMA

2. ISPEC Uluslararası Bilimsel İş Birliği ve Disiplinlerarası Araştırmalar Kongresi 02-07 Eylül 2026 tarihleri arasında Budapeşte / Macaristan'da 23 farklı ülkenin (Türkiye-93, Diğer Ülkelerden-128) akademisyen/araştırmacılarının katılımıyla gerçekleşmiştir. Kongre 16 Ocak 2020 Akademik Teşvik Ödeneği Yönetmeliğine getirilen "Tebliğlerin sunulduğu yurt içinde veya yurt dışındaki etkinliğin uluslararası olarak nitelendirilebilmesi için Türkiye dışında en az beş farklı ülkeden sözlü tebliğ sunan konuşmacının katılım sağlaması ve tebliğlerin yarıdan fazlasının Türkiye dışından katılımcılar tarafından sunulması esastır." değişikliğine uygun düzenlenmiştir.

Bilgilerinize arz edilir,

Saygılarımla



Assoc. Prof. Dr. Muhammet Ali GÜNDEŞLİ
PRESIDENT OF THE CONGRESS