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17th INTERNATIONAL CONFERENCE ON ENGINEERING & NATURAL SCIENCES

May 03-07, 2025 / Prague, Czechia

CONFERENCE PROCEEDINGS BOOK

Editor: Assist. Prof. Dr. Yeter Çilesiz

17th INTERNATIONAL CONFERENCE ON ENGINEERING & NATURAL SCIENCES

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PROCEEDINGS BOOK
(Abstracts & Full Texts)

EDITOR
Assist. Prof. Dr. Yeter ÇİLESİZ

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17th INTERNATIONAL CONFERENCE ON ENGINEERING & NATURAL SCIENCES

EVALUATION PROCESS and POLICIES

All applications have undergone double blind peer review process. In addition, each paper was accepted and the process of publishing in the book was carried out through editorial oversight. The published papers were presented and discussed at the meeting.

Full texts and abstracts published in accordance with the Symposium Policy have been prepared in accordance with ethical rules and APA standards. Authors of all papers are both ethically and legally responsible.

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Türkiye, Albania, Algeria, Azerbaijan, Bangladesh, Bulgaria, Ethiopia, Georgia, India, Indonesia, Iran, Kazakhstan, Malaysia, Morocco, Nigeria, Pakistan, Philippines, Saudi Arabia, Slovenia, Sri Lanka, Uganda, Ukraine

TOTAL ACCEPTED ARTICLES: 306

The Number of Accepted Papers from Türkiye: 113
The Number of Accepted Full Papers from Other Countries: 123
The Number of Total Papers: 236

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CONGRESS PROGRAM

Online (with Video Conference) Presentation

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04.05.2025
Prague Local Time: 18:00-19:30

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IN-PERSON SESSION

Veue: Grand Hotel International Prague
HALL-1

MODERATOR: Ercan CEYHAN

AUTHOR	AFFILITION	ABSTRACT TITLE
Ercan Ceyhan Serdar Karadaş	*Selçuk University*	Six-Year Trend Of Red Lentil Production In Turkiye: Cultivation Areas, Productivity, And Market Balance
Ercan Ceyhan Serdar Karadaş	*Selçuk University*	From Drought To Trade: Five Years Of Chickpea Cultivation In Türkiye
Tefaruk Haktanır	*Erciyes University*	On-Site Determination Of Concrete Strength By Direct And Indirect Methods
Semra Benzer Recep Benzer Farid Hassanbaki Garabaghi Batuhan Görkem Benzer	*Gazi University*	Machine Learning Approaches In Classifying And Analyzing Atherina Boyeri
Mehmet Demir Raşit Köker	*Sakarya University of Applied Science*	Development Of Brain Computer Interface Software Based On Detection Of Eeg Signals With New Generation Sensors
Ibrahim Özcan Hakan Alıcı Parham Taslimi Hakan Tahtacı	*Zonguldak Bülent Ecevit University*	Novel 1,2,4-Triazole-Derived Schiff Base Derivatives: Design, Synthesis, And Multi-Enzyme Targeting Potential For Therapeutic Applications
Kağan Tolga Cinisli Hayrunisa Nadaroğlu Ufuk Okkay Ahmet Hacımüftüoğlu	*Atatürk University*	Next-Generation Vaccines And In Silico Analyses: A New Era In Immunization
Cihat Gedik Bahadır Sayıncı Taner Yıldız	*Bilecik Seyh Edebali University*	Strawberry Flower Detection Using The Haar Cascade Algorithm
Alper Baydar Yeşim Bozkurt Çolak	*Siirt University*	Determination Of The Effects Of Different Irrigation Levels And Fertigation Applications On Stoma Resistance And Yield In Tomato Plant
Oğulcan Eren Nurullah Yüksel Neslihan Top	*Gazi University*	Sustainability Perspectives In Additive Manufacturing Of Resin-Based Composite Materials
Neslihan Top Tolgahan Şahin Mert Efe Ceylan Ramazan Çakiroğlu Ismail Şahin	*Gazi University*	Effect Of Printing Orientation And Heat Treatment Combination On Surface Quality In Material Extrusion Additive Manufacturing Of Metals (Mex/M): A Literature Review
Melek Güner Hilal Incebay	*Batman University*	Polystyrene/Tio_2 Nanocomposites: A Study On Dielectric Properties

04.05.2025
Prague Local Time: 18:00-19:30

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IN-PERSON SESSION

Veue: Grand Hotel International Prague
HALL-2

MODERATOR: Tolga KARAKÖY

AUTHOR	AFFILITION	ABSTRACT TITLE
Halime Ilayda Doğan Ahmet Mavi	*Gazi University*	Bibliometric Analysis On The Machinability Of Inconel 718 Alloy
Çağlasin Yaldız	*Kırklareli University*	An Evaluation Of The Typicality Of The Crime Of Simple Sexual Assault And Its Trial Procedures
Volkan Yamaçli Habibe Elif Gülşen Akbay Halil Kumbur	*Mersin University*	Early-Stage Weed Detection And Classification From Uav Imagery Using A Local-Origin Software System
Ismail Kutlugün Akbay Habibe Elif Gülşen Akbay	*Mersin University*	Synthesis Of Okra Gum-Based Smart Hydrogel
Sercan Acarer Kader Sever Can Çivi	*İzmir Katip Çelebi University*	Heat Transfer And Energy Analysis Of An Industrial Ironing Machine
Memduha Ergüt	*Sivas University of Science and Technology*	Heterogeneous Fenton-Like Degradation Of Tetracycline By SBA-15/Fe-Co NPs Composite Material Synthesized Using Black Mulberry (*Morus nigra* L.) Leaves Extract
Memduha Ergüt	*Sivas University of Science and Technology*	Punica Granatum (Pomegranate) Peel Extract Mediated Green Synthesis And Characterization Of Magnetic Spinel Copper Ferrite ($CuFe_2O_4$): Sono Fenton-Like Decolorization Of Reactive Red 2
Tolga Öztekin Metehan Atagür Kutlay Sever	*İzmir Kâtip Çelebi University*	Thermal, Crystallographic, And Morphological Analysis Of Marble Powder And Kaolin Reinforced Hybrid Composites
Tolga Öztekin Metehan Atagür Kutlay Sever	*İzmir Kâtip Çelebi University*	Mechanıcal And Vıscoelastıc Propertıes Of Marble Powder Fılled Polypropylene Composıtes
İpek Abasıkeleş Turgut	*İskenderun Technical University*	An Event-Based Traffic Management Application In Vanets
Berk Özler Serdar Yıldırım	*Izmir Katip Celebi University*	Viscoelastic And Thermal Performance Of 3d-Printed Sio 2 Nanocomposites: Influence Of Silane Modification On Reinforcement Efficiency
Kübra Nur Gülfidan Müsüm Özışık Selvi Durmuş	*Yildiz Technical University*	Stochastic Perturbed (2+1)-Dimensional Biswas-Arshed Equation And Stochastic Optical Soliton Solutions Under The Effect Of White Noise
Mahmut Kaplan Selim Özdemir Kağan Kökten	*Erciyes University*	Comparison of Different Maize Varieties for Silage Nutritional Properties
Mahmut Kaplan Mahmood Eshaqzai Beyza Çiftci İhsan Serkan Varol	*Erciyes University*	The Effects of Support Irrigation and Nitrogen Doses on Wheat Yield and Yield Characteristics in Summer Wheat at Different Developmental Periods
Selim Özemir Kağan Kökten Mahmut Kaplan	*Erciyes University*	Determination of Nutritional Properties of Plant Parts in Maize Cultivars

Sema Kaplan	*Erciyes University*	Effects of Different Zeolite Ratios on Some Soil Properties in Light and Heavy-Textured Soils

04.05.2025
Prague Local Time: 19:45-21:30

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IN-PERSON SESSION

Veue: Grand Hotel International Prague
HALL-1

MODERATOR: Hatice BEKÇİ

AUTHOR	AFFILITION	ABSTRACT TITLE
Duygu Gürkan Büşra Çalik Selçuk Yağmur Gültekin Uzun Ihsan Korkut	*Gazi University*	The Effect Of Printer Parameters On Flatness In Samples Produced With Fdm Method
Büşra Çalik Duygu Gürkan Selçuk Yağmur Gültekin Uzun	*Gazi University*	Investigation Of The Effect Of Process Parameters On The Mechanical Strength Of Pla Specimens Produced By Fdm
Mustafa Özgür Yaylı Hayrullah Kadioğlu	*Bursa Uludag University*	A Mathematical Method Finding The Vibration Frequencies Of A Viscoelastic Beam
Mustafa Tunçsoy Benay Tunçsoy	*Çukurova University*	Investigation Of The Effects Of Different Sizes Of Aluminum Oxide On Tissue Accumulation Of Oreochromis Niloticus
Gonca Çelikten	*Kafkas Üniversitesi*	An Implicit Exponential Scheme For Solving The Time-Fractional Newell–Whitehead–Segel Equation
Hatun Erkuran	*Gümüşhane University*	Evaluation Of Health Services Vocational School Students' Knowledge And Attitudes About Vaccination And Vaccination Refusal
Servet Üztemur Ali Gökalp Tuba Çengeci Köse	*Anadolu University*	How Does Self-Control Affect Financial Literacy? A Cross-Sectional Study On Middle School Students
Gizem Tiryaki Emine Nakilcioğlu	*Ege University*	Protein Isolation From Ulva Species: Comparison Of Extraction Methods
Bahar Kuloğlu Alper Polat	*Sivas University of Science and Technology*	Quantum-Like Encryption Supported By Randomness Based On Fibonacci And Kakutani
Bahar Kuloğlu Engin Özkan	*Sivas University of Science and Technology*	Analysis Of R-Circulant Matrices Constructed From K-Fibonacci And K-Lucas Quaternions: Norms And Eigenvalue Properties

04.05.2025
Prague Local Time: 19:45-21:30

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IN-PERSON SESSION

Veue: Grand Hotel International Prague
HALL-2

MODERATOR: Yusuf SERT

AUTHOR	AFFILITION	ABSTRACT TITLE
Esin G. Canlı Mustafa Canlı	*University of Cukurova*	The Responses Of Biomarkers Belonging To Different Metabolic Systems Of Freshwater Mussels (Unio Tigridis) Following Cadmium Exposures
Esin G. Canlı Nagihan Pepe Mustafa Canlı	*University of Cukurova*	Effects Of Metal-Oxide Nanoparticles On The Antioxidant And Osmoregulation Systems Of Freshwater Fish (Oreochromis Niloticus) In Differing Salinities
Aydın Seçer Ismail Önder Müslüm Özışık Mustafa Bayram Neslihan Özdemir Melih Çınar Hasan Çakıcıoğlu Handenur Esen Selvi Durmuş	*Yıldız Technical University*	On Optical Soliton Solutions Of Perturbed Fokas-Lenells Equation Having Parabolic Law With Nonlocal Nonlinearity In The Presence Of Spatio-Temporal Dispersion
Ibrahim Dağlı	*Independent Researcher*	Revisiting The Growth Dynamics Model In Artificial Intelligence Technologies: Empirical Evidence Through Panel Data Econometrics
Bahadır Demirel Gürkan Alp Kağan Gürdil Adem Güneş Yusuf Murat Keçe	Erciyes *University*	Investigation Of Possibilities Of Producing Biodegradable Organic Growing Media For Plant Production Using A Resigned Hydraulic Press
Bahadır Demirel Gürkan Alp Kağan Gürdil Adem Güneş	Erciyes *University*	Investigation Of Possibilities Using Snack Pumpkin Vegetable Wastes In Pellet Biomass Production
Hakan Çelikten Arslan Saral Gülten Güneş	Kafkas University	Seasonal And Spatial Distribution Of Pcb Concentrations In The Atmosphere Of A Metropolitan City: Istanbul, Turkey
Hakan Çelikten	Kafkas University	Microplastics And Their Impacts In Aquatic Ecosystems
Bahadır Demirel Adem Güneş	*Erciyes University*	Effects Of Triacontanol Applications On Pellet Fertilizer Content And Efficiency
Adem Güneş Bahadır Demirel	*Erciyes University*	Effect Of Triacontanol On Plant Growth
Kevser Karagöz Sezer Mehtap Öztekin Necati Şimşekli	*Republıc Of Türkiye Mınıstry Of Agrıculture And Forestry Fıeld Crops Central Research Institute*	Investigation of the Effects of Climate Change on the Phenology of Certain Species (Ephedra major subs. major – Hum or Sea Grape, Atriplex canescens (Pursh) Nutt. –Fourwing Saltbush) and Determination of Their Habitat Requirements in the Konya Karapınar Desert Ecosystem – First Detection

04.05.2025
Prague Local Time: 21:30-23:00

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IN-PERSON SESSION

Veue: Grand Hotel International Prague
HALL-1

MODERATOR: Mehmet Fırat BARAN

AUTHOR	AFFILITION	ABSTRACT TITLE
Mehmet Fırat Baran	*Siirt University*	Energy Potential From Animal Wastes (The Case Of Edirne Province)
Halil Kineyn Mehmet Fırat Baran	*Siirt University*	Carbon And Water Footprint Latest Discoveries, Global Impacts And Innovative Solutions For The Future Of Our Planet
Umay Büşra Celiloğlu Raziye Pekşen Akça	*Kayseri University*	The Educational Value and Application of Biophonic Sounds in Early Childhood Education
Raziye Pekşen Akça Umay Büşra Celiloğlu	*Kayseri University*	Okul Öncesi Eğitimde Doğa Tabanli Materyallerin Yapay Zekâ Destekli Öğrenme Deneyimlerine Entegrasyonu
Tolga Karaköy Ömer Sözen	*Sivas University of Science and Technology*	Evaluation Of The Performance Of Some Sainfoin (*Onobrychis Sativa* L.) Cultivars Under The Ecological Conditions Of Sivas
Ömer Sözen Tolga Karaköy	*Sivas University of Science and Technology*	A Study On The Morphological And Yield Characteristics Of Different Alfalfa (*Medicago Sativa* L.) Cultivars Under The Ecological Conditions Of Sivas Province
Yusuf Sert	*Yozgat Bozok University*	DFT Computations Of N-ETHYL-P-Toluenesulfonamide (NEPTS)
Yusuf Sert	*Yozgat Bozok University*	Docking Analysis Of N-ETHYL-P-Toluenesulfonamide (NEPTS)

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IN-PERSON SESSION

Veue: Grand Hotel International Prague
HALL-2

MODERATOR: Yeter Çilesiz

AUTHOR	AFFILITION	ABSTRACT TITLE
Tuğba Dedebaş Meryem Göksel Saraç	*Afyon Kocatepe University*	Investigation Of The Utilization Possibilities Of Duckweed (Lemna Minor) As A New Protein Source
Meryem Göksel Saraç Tuğba Dedebaş	*Afyon Kocatepe University*	Properties And Uses Of The Herb Curmen (Allium Scorodoprassum L.), Known As Wild Garlic
Ebru Yabaş	*Cumhuriyet University*	Graphene Based Sensor Technology
Ebru Yabaş Seval Elden Ürgüp	*Cumhuriyet University*	Energy Efficiency and Financial Performance in Chemical Production
Hatice Bekçi	*Kayseri University*	Aronia Bitkilerinin Kanser Aktiviteleri Üzerine Etkileri
Hatice Bekçi	*Kayseri University*	Molehia Bitkisinin Kanser Aktiviteleri Üzerine Etkileri
Yeter Çilesiz	*Sivas University of Science and Technology*	DNA and RNA Based Diagnostic Methods for Plant Diseases
Yeter Çilesiz	*Sivas University of Science and Technology*	Protein Based Diagnostic Methods for Plant Diseases
Yeter Çilesiz	*Sivas University of Science and Technology*	Next Generation Sequencing (NGS) and Metagenomic Approaches for Detection of Plant Diseases
Yeter Çilesiz	*Sivas University of Science and Technology*	CRISPR/Cas System Based Diagnostic Methods for Plant Diseases

03.05.2025
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SESSION-1, HALL-1 / OTURUM-1, SALON-1

MODERATOR: Şahin Özel

Meeting ID: 844 6001 0824
Passcode: 030405

AUTHOR	AFFILITION	ABSTRACT TITLE
Md. Salah Uddin Neaz A. Hasan	*Gopalganj Science and Technology University*	Impacts of tropical cyclone Sitrang on the shrimp industry: A case study from the coastal region of Bangladesh
Anand Mahendran Ronit Debnath Anurag Velekat Marian George	*Vellore Institute of Technology*	Bio-sequence Analyzer: A Tool for Classification of Bio-molecular Structures
Simay Hepkeskin Şahin Özel Asım Olgun Mesut Görür	*Bursa Uludağ University*	Development Of Adhesives Containing Poly(Glycidyl Methacrylate-Co-Methyl Methacrylate) Coopolymer And Investigation Of The Effect Of Heat-Treated Boric Acid On The Adhesive Performance
Asım Olgun Mesut Görür Şahin Özel Zeynep Atalay	*Bursa Uludağ University*	Investigation Of The Adhesion Performance Of Composite Adhesives Obtained By Adding Calcined Tincal To Polymeric Epoxy Adhesives
Asım Olgun Mesut Görür Şahin Özel Ogün Özdemir	*Bursa Uludag University*	Synthesis Of Calcined Colemanite Additive Polymer Composite Adhesives And Investigation Of Their Adhesion Performance
Şahin Özel Asim Olgun Mesut Görür	*Bursa Uludag University*	Synthesis, Characterization, And Investigation Of Adhesive Applications Of Epoxy-Containing Polymeric And Polymeric Composite Materials
Thura Ali Khalaf Gölge Ögücü Yetkin	*Gaziantep University*	Parasitic Antenna Array With Wide Scanning Coverage For 5g Applications
Bashir, M.B Faruk, A.U Isah, S Lukman, A	*Ahmadu Bello University*	Access and Utilization Patterns of Agricultural credit among Smallholder Maize farmers in Bida Local Government area, Niger State
C. Bala Sai K.Tharani Nadagouda Kalyani	*G Pulla Reddy Engineering College*	Technology For Sustainable Concrete

03.05.2025
Prague Local Time: 09:00-11:00
Ankara Local Time: 10:00-12:00

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SESSION-1, HALL-2 / OTURUM-1, SALON-2

MODERATOR: Derya Kaman

Meeting ID: 844 6001 0824
Passcode: 030405

AUTHOR	AFFILITION	ABSTRACT TITLE
Muammer Zengin Fatih Serdar Sayın Mustafa Şengör Talha Kılıç	*Marmara University*	A Microcontroller-Based Fiber-Optic Data Communication Module For Transmitting Data Between Two Computers
Yusuf Tahir Altuncı	*Isparta University of Applied Sciences*	Use Of Andesite Powder And Brick Powder As Cement Replacement Materials
Huma Ikram Rumaisa Zakir Darakhshan J. Haleem	*University of Karachi*	Memory Enhancing And Neuroprotective Effects Of Apomorphine In A Rat Model Of Dementia
Ilyass El Kadmiri Younes Errouas Ilham El-Atmani Youssef Ben-Ali Driss Bria	*Sidi Mohamed Ben Abdellah University*	AIT resonance and Flat Band in 1D Acoustic Quasi-Periodic structure
Buse Nur Tapan Asim Olgun Mesut Görür Sahin Özel	*Bursa Uludağ University*	Synthesis and Characterization of Metal-Metal Polymeric Adhesives and Investigation of the Effect of Composite Forms on Bonding Performance
Derya Kaman	*Kayseri University*	Üniversite Öğrencilerinin Dijital Bağımlılığa İlişkin Metaforik Algıları
Ayesha Batool Arif Gull Farkhanda Anjum Hafsa Naeem Rimsha Anwar Zainab Fatima	*Islamia University*	The Role of AI in Promoting Equitable Access to Clean Water in Rural Communities
S. Reashmi S. Selvam	*Kamaraj College of Engineering and Technology*	An Efficient Storage Optimization Techniques for Large Database
Vanitha A Tamilmani E.P Swetha sree S Shiphrah Joyce D Sathya M S Lalitha Ramachandran	*R.M.K. Engineering College Thiruvallur,India*	Application of Neurocomputing in Adaptive Control of Large Scale Aerospace Systems

03.05.2025
Prague Local Time: 09:00-11:00
Ankara Local Time: 10:00-12:00

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SESSION-1, HALL-3 / OTURUM-1, SALON-3

MODERATOR: Irem Uzunsoy

Meeting ID: 844 6001 0824
Passcode: 030405

AUTHOR	AFFILITION	ABSTRACT TITLE
Kadir Güçlüer	*Adıyaman University*	An Investigation of the Effect of Different Types of Sound Insulation Application on Sound Reduction in Building Floors and Walls
Irem Uzunsoy	*Zonguldak Bulent Ecevit University*	Nanotechnology And Dairy Industry: Prospects And Challenges
Mouhajar Siham Youssefi Abdelkader	*Hassan 1 University*	IoT-Based Prototype for Industrial Equipment Monitoring and Predictive Maintenance
Shahid Adeel Talha Khan Mahwish Salman Nimra Amin Noman Habib	*Government College University*	Chemical Mordanting For Natural Dyeing Of Fabrics
Mehmet Ufuk Aslan Garip Yarşı Hakan Arslan	*Mersin University*	Fertilizer Potential Of Zeolites; A Greenhouse Experiment
Warda Waseem Muhammad Yasin Naz Abdul Ghaffar	*University of Agriculture Faisalabad*	Comparative Study Of Titanate-Based Perovskite Oxides For Energy Storage Devices
Pooja Rasal Gaurav Kasar	*JES's SND College of Pharmacy*	Aptamer: A Targeted Cancer Immunotherapy
Suganthi S Yathra Tamizhazhagi Sanjana Sripriya	*RMK Engineering College, Thiruvallur*	Industrial Health Monitoring System for DC Motors
Shubham Sharma Sunil Gupta	*Mangalayatan University Aligarh*	Formulation and Evaluation of Neem, Turmeric, and Tea Tree Oil- Based Emulgel and Its Evaluation for Antifungal Activity

03.05.2025
Prague Local Time: 09:00-11:00
Ankara Local Time: 10:00-12:00

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SESSION-1, HALL-4 / OTURUM-1, SALON-4

MODERATOR: Ali Baran Narin

Meeting ID: 844 6001 0824
Passcode: 030405

AUTHOR	AFFILITION	ABSTRACT TITLE
Thura Ali Khalaf Gölge Ögücü Yetkin	*Gaziantep University*	Design And Analysis Of Microstrip Patch Antenna Using Two Feeding Methods For 5g Applications
K.Thamizhmaran	*Government College of Engineering, Bodinayakkanur, Theni*	Msbehavior Node in Wireless Mobile Ad hoc Networkss
Mohcin Elkhatir Ismail Louragli Abdechahid Loukili Youssef Aboussaleh	*Ibn Tofail University*	Relationship Between Organic Food Consumption And Attention Performance In A Sample Of Moroccan Primary School Students From Khemisset
Rifa Tamanna Mona M Mahfuzur Rahman Obaidur Rahman Md. Yeamin Hossain	*University of Rajshahi*	Estimation Of Population Parameter For Tank Goby Glossogobius Giuris (Hamilton, 1822) From The Rani River In Northwestern Bangladesh Throughs The Multimodal Approaches
Ali Baran Narin Hakan Arslan	*Mersin University*	Effects Of Activation And Modification On Zeolite-Based Slow-Release Fertilizers
Stanislava Stateva	*Institute of Plant Genetic Resources*	Development Of Technology For In Vitro Propagation And Storage of Atropa belladonna L.
Zineb El Hamri M. Karaoui M. Alami M. Assouag	*University Moulay Ismail*	The Impact Of Adding Walnut Shell Powders On The Morphology, Thermal Properties, And Mechanical Performance Of Poly(lactic acid) (PLA)
Amira Kharkhache Souad Abdellaoui Douaa Slimani Imane khamlichi Rajae Mouedden Nassir Kaddouri Mohamed el yaakoubi Youssef Smiri	*Laboratory for the Improvement of Agricultural Production, Biotechnology and the Environment*	Scientific analysis of the vulnerability of Chamelea gallina to exploitation and environmental changes

03.05.2025
Prague Local Time: 09:00-11:00
Ankara Local Time: 10:00-12:00

(All speakers required to be connected to the session 15 min before the session starts)
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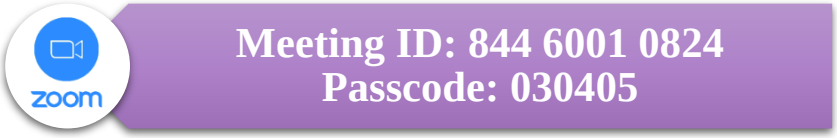
SESSION-1, HALL-5 / OTURUM-1, SALON-5

MODERATOR: Tuğba Ergenç



AUTHOR	AFFILITION	ABSTRACT TITLE
Zineb El Hamri M. Karaoui M. Alami M. Assouag	*University Moulay Ismail*	The Effects of NaOH Pretreatment, Thermal Pretreatment, And Their Combined NaOH- Thermal Method On Biomethane Production During The Anaerobic Digestion Of Walnut Shells
Said Babou Miloud Chakit Abdelhalem Mesfioui Moulay Laarbi Ouahii Youssef Sqalli Houssaini	*Ibn Tofail University*	Neuroprotective Effects Of Rosmarinus Officinalis Ethanolic Extract On Cognitive- Affective Functions And Hippocampus Oxidative Stress In Wistar Rats Exposed To Cadmium
Said Babou Miloud Chakit Abdelhalem Mesfioui Youssef Sqalli Houssaini	*Ibn Tofail University*	Dose-dependent Effects of Cadmium on Anxiety-Like and Depressive-Like Behaviors and Oxidative Stress in the Prefrontal Cortex of female Rats
Gherbi S. Bouhadiba S. Saidi Ouahrani N. Berrebbah Alioua A.	*Université des Sciences et de la Technologie d'Oran-Mohamed Boudiaf USTO-MB*	Assessment of Metal Pollution and Physical Condition Using a Biological Bioindicator: The Atlantic Horse Mackerel Trachurus trachurus Caught Along the Oran Coastline
Tuğba Ergenç	*Van Yüzüncü Yıl University*	Effect Of Hormones On Endometriosis
Ilkün Orbak	*Maltepe University*	Inventory Management In Factory Automation: An Application On Critical Material Classification With Abc Analysis
Abdellah Bahtat	*Sidi Mohamed Ben Abdellah University*	Medical Responsibility In The Digital Age
Soltani Fatiha Benabdelmoumene Djilali Bengharbi Zineb Benguennouna Noureddine	*Applied animal physiology lab, Abdelhamid IbnBadis Mostaganem*	The impact of incorporating eucalyptus oil into the diet of broiler chickens

03.05.2025
Prague Local Time: 11:30-13:30
Ankara Local Time: 12:30-14:30

(All speakers required to be connected to the session 15 min before the session starts)
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SESSION-2, HALL-1 / OTURUM-2, SALON-1

MODERATOR: Hatice Kaçuş

Meeting ID: 844 6001 0824
Passcode: 030405

AUTHOR	AFFILITION	ABSTRACT TITLE
Ahmed Attahiru Abubakar Umar Birnin Yauri Hannatu Abubakar Sani	*Kebbi State* *University Of Science And Technology*	Medicinal Applications Of Alkaloids Compounds
Hatice Kaçuş	*Ardahan University*	Analysis Of Electrical Characteristics Of Silver And Gold Nanoparticles Interface Layers On Silicon At Schottky Diodes
Cagla Gizem Acar Audrius Zunda	*Vytautas Magnus University*	Tribological Assessment Of Graphene At Macro, Micro, And Nanoscale
Muhammet Burak Gözütok Mustafa Çanakcı	*Kocaeli University*	Theoretical Investigation Of The Performance And Environmental Impacts Of Compressed Natural Gas (Cng) In Internal Combustion Engines
Shumaila Naz	*University Of Karachi*	Evolutionary History Of Vertebrates
Taskeen Fatima Mahna Fatima Areeba Arif Mehran Majeed Raheela Muqadus	*Hajvery University*	Formulation And Evaluation Of Otf Of Cetirizine For Rapid Systemic Action
Taskeen Fatima Mehran Majeed Mahna Fatima Raheela Muqadus Areeba Arif Nabiha Iqbal Mah-Ru-Nisa Atif	*Hajvery University*	Correlation Study On Etiological Factors Of Heart Disease In Diabetic Patients In Lahore, Pakistan
Usman Aliyu Taliyawa Jabir Mohammed	*Modibbo Adama University*	Assessment Of Municipal Solid Waste Generation And Management Strategies In Gombe Metropolis, Gombe State, Northeastern Nigeria
Aliyu Hassan	*Air Force Institute Of Technology, Nigerian Air Force, Kaduna*	Assessing The Impacts Of Unregulated Solid Waste Disposal In Kaduna City, Nigeria

03.05.2025
Prague Local Time: 11:30-13:30
Ankara Local Time: 12:30-14:30

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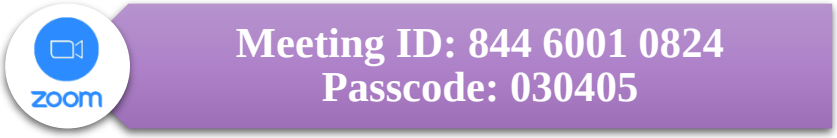
SESSION-2, HALL-2 / OTURUM-2, SALON-2

MODERATOR: Ayşen Işık



AUTHOR	AFFILITION	ABSTRACT TITLE
Mohd Vaseem Amandeep Singh Grover Akhtarul Islam Amjad	*National Institute of Fashion Technology, Panchkula, India*	Cloth size prediction with AI: Decision tree
Hung Wei Yi Andrea Lehoczki Mónika Fekete Zoltán Ungvári	*Semmelweis University*	The impact of the Mediterranean diet on autoimmune diseases: a systematic review and analysis
Semanur Balkan Ayşen Işik Ahmet Koçak	*Selcuk University*	Synthesis And Characterization Of A New 1,3,4-Thiadiazole-Hydrazone Derivative
H. A Sani U.B Shalla I.S Shabanda A.U Birnin Yauri M. Muhammad	*Kebbi State University of Science and Technology*	Green Synthesis of Calcium Carbonate Nanoparticles (CaCO3 NPs) from Waste Eggshells using Neem Extract: A Sustainable Approach to Nanomaterial Production
Aloui Mourad Menana Elhalaoui	*Sidi Mohamed Ben Abdellah University*	Development and Assessment of New MX-106 Hydroxyquinoline Derivatives: 2D-QSAR Analysis, Molecular Docking, Dynamics Simulations, and ADMET Predictions for Targeted Survivin Inhibition
Shakul Hameed N V. Rakshana R. Srinivasan	*Bharath Institute of Higher Education and Research*	Evaluating The Safety And Toxicity Profile Of Ashwagandha
A.N. Bhavale A.P. Bachate S.A. Suryawanshi A.B. Daundkar	*PES Modern college of Arts*	Verification Of Counting Of Lattices
Mohamed Bakir Abdelkader Youssefi Rachid Dakir Mouna El Wafi Younes El Koudia	*Hassan First University of Settat*	Improving Highway Safety with Automated Lane Change Using Sensor Fusion and Trajectory Planning

03.05.2025
Prague Local Time: 11:30-13:30
Ankara Local Time: 12:30-14:30

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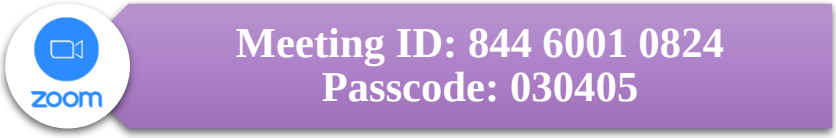
SESSION-2, HALL-3 / OTURUM-2, SALON-3

MODERATOR: Uğur Ejder



AUTHOR	AFFILITION	ABSTRACT TITLE
Canan Hacioglu Enes Kurtulus Cagatay Elibol Kadir Sagir	*Coşkunöz Metal Form Sanayi ve Ticaret Anonim Şirketi*	Development Of Multilayer Tribological Dlc Coating Systems For Cold Stamping Processes
Anıl Şeker Furkan Değirmencioğlu Cihan Kaboğlu	*Sanver Mühendislik Tasarım Merkezi*	Investigation Of The Suitability Of Two Different Metal Materials For Laser Welding Depending On Process Parameters
Narmin Habilova Khizri Sakhrayev	*Azerbaijan State Economic University*	Drivers And Environmental Impacts Of Deforestation In Eastern Europe: A Literature Review
Uğur Ejder	*Adana Alparslan Türkeş Science and Technology University*	Tastegan: Gan-Based Flavour Enhancement And Quality Predicting Model
Adenike Mercy Ajayi Adesiyan Oyinade Funke	*Federal Polytechnic, Ilaro, Ogun State, Nigeria*	The Collapse of Individualism: Exploring the Dangers of Isolation in the Quest for Peace in Niyi Osundare's Not My Business
Vardhana Janakiraman N. Rithika N. Pavithra Pratip Mandal S. Arut Selvam N. K. Udaya Prakash	*Vels Institute of Science*	Fungal Diversity Of Soils Of Pine Forest
A.N. Bhavale S.S. Mundekar P.V. Kule K.K. Shete	*PES Modern college of Arts, Science and Commerce*	Hasse Diagrams Of Basic Blocks Containing 4 Comparable Reducible Elements And Having Nullity Five
A. N. Bhavale P. A. Parate P. H. Tupte S. V. Shirsath	*PES Modern college of Arts, Science and Commerce*	Hasse Diagrams Of Basic Blocks Containing Four Comparable Reducible Elements And Having Nullity Four

03.05.2025
Prague Local Time: 11:30-13:30
Ankara Local Time: 12:30-14:30

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SESSION-2, HALL-4 / OTURUM-2, SALON-4

MODERATOR: Etibar Vazirov

Meeting ID: 844 6001 0824
Passcode: 030405

AUTHOR	AFFILITION	ABSTRACT TITLE
O. A. Odebiyi W.O.Salahu A.O. Areo T.O. Oluyo	*Ladoke Akintola University of Technology*	Mathematical Modeling Of Hiv/Aids Investigating The Effect Of Inconsistent Treatment With Nonlinear Incidence
Ajiwe, S. T. Lawal, I. T. Olanrewaju, O. R. Ganiyu, C.P., Adeniyi, R. Y	*Ajayi Crowther University*	Efficacy Of Cashew Based Compost On Fusarium Wilt And Fruit Yield Of Tomato (Solanum Lycopersium L.)
Gamze Doğan Selçuk Karagöz	*Bursa Techinical University*	Investigation Of Edge Crack Parameters Of High Strength Steels
Etibar Vazirov Zahra Baghirzada Ayan Nazaraliyeva	*ADA University*	Forecasting And Optimizing Renewable Energy Storage Efficiency In The Era Of Climate Change
Etibar Vazirov Nijat Taghizadeh Tural Abdinli	*ADA University*	Predicting Forest Fire Risks Using Explainable Ai And Satellite Data: A Random Forest And Shap-Based Approach
Etibar Vazirov Farid Mirzaliyev	*ADA University*	Predicting Student Mental Health Using Machine And Deep Learning Approaches
Monika Stojanova Sani Demiri Marina Todor Stojanova Dragutin A. Djukic	*Mother Teresa University*	Advancing Agricultural Sustainability: The Role Of Nano Fertilizers In Enhancing Food Quality And Safety

03.05.2025
Prague Local Time: 11:30-13:30
Ankara Local Time: 12:30-14:30

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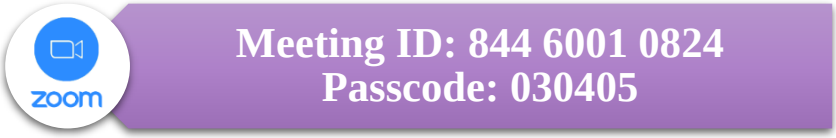
SESSION-2, HALL-5 / OTURUM-2, SALON-5

MODERATOR: Melis Nur Canpulat



AUTHOR	AFFILITION	ABSTRACT TITLE
Melis Nur Canpulat	*ZKLD Studio*	Dark Sky: Engineering The Future Of Light With Sustainability In Mind
Amrouche Zoheir Fauconnier Marie-Laure Laribi-Habchi Hassiba	*University of Khemis Miliana- Algeria*	Phenolic profile and antimicrobial activity of Rosmarinus officinalis in different Algerian region
Didem Aksu Basri Aksu Güven Özdemir	*Ege University*	Molecular Characterization And Determination Of Amylase-Protease Activity Of Bacterial Isolates From Septic Tank
Aslı Arslan Süreyya Aydin Yüksel	*Yıldız Technical University*	Cuo/Ps/Nsi Schottky Diode Structured Non-Enzymatic Glucose Sensors
Özcan Ateş Fadullah Yıldırım	*Rollmech Automotive*	Investigation Of Contact Corrosion Between Aluminum Hinges And Steel Body In Commercial Vehicles Using Different Protection Methods
Gheorghe Giurgiu Manole Cojocaru	*Deniplant-Aide Sante Medical Center*	My Patient Has Signs Of Psoriasis: How Concerned Should I Be And What Should I Do?
R. Kamali S. Aadhithra S. Dharshini	*Department of electrical and electronics engineering in R.M.k group of institutions*	Applications of Laplace and Inverse Laplace Transforms in Electrical Engineering for Analyzing and Solving Circuit Differential Equations
Rajani V Krishnaveni S Manasi Manoj Ayona Jayadev	*Research Centre and Post Graduate Department of Environmental Sciences*	Analysis Of Comparative Concentrations Of Microplastics In Soil And Plant Organs

03.05.2025
Prague Local Time: 14:00-16:00
Ankara Local Time: 15:00-17:00

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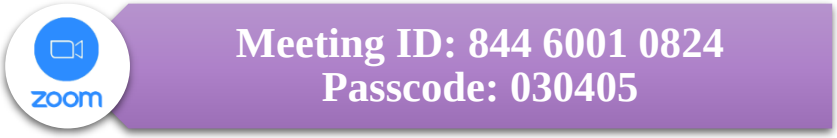
SESSION-3, HALL-1 / OTURUM-3, SALON-1

MODERATOR: Irem Odabası



AUTHOR	AFFILITION	ABSTRACT TITLE
Jatin Ajesh Chauhan Chetan Vashisht Arun Mittal	*Hindu College of Pharmacy, Sonipat*	Integrating traditional and Modern medicine in healthcare system
Kadir Danışmaz Mücahit Kocataş	*ZF Lemförder*	Relation Between Damage Rate & Connection Loosening Performance: Evaluation Of Calculation & Validation
Mustafa Can Hacıoğlu	*Karabuk University*	Data Envelopment Analysis Application In Textile Industry
Irem Odabası Bahadır Gulsun Irem Otay	*Yıldız Technical University*	Price Elasticity Analysis In A Double Machine Learning Framework: An Improved Methodological Model
Tanveer Hussain Bokhari Muhammad Khalid	*Government College University*	Preparation and Biodistribution of 90 Y-EDTMP for Bone Seeking Therapeutic Agent
Eny Martndah Sutiastuti Wahyuwardani Susan Maphilindawati Noor Andriani Andriani Wasito Wasito Sri Suryatmiati Prihandani Riyandini Putri Patriantariksina Randusari Raphaella Widiastuti	*The National Research and Innovation Agency, Cibinong Science Centre*	Smallholder Farmers' Awareness Of Brucellosis In Small Ruminants In Urban Areas Of Jakarta, Bekasi, And Bogor, Indonesia
Nitul Ali Bikash Bania	*Department of Zoology Rangia College, Rangia*	Epidemiological Profile and Public Health Risks of Zoonotic Diseases in Assam, India: A One Health Perspective

03.05.2025
Prague Local Time: 14:00-16:00
Ankara Local Time: 15:00-17:00

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SESSION-3, HALL-2 / OTURUM-3, SALON-2

MODERATOR: Tuba Terbıyık Kurt

Meeting ID: 844 6001 0824
Passcode: 030405

AUTHOR	AFFILITION	ABSTRACT TITLE
Zeynep Sirel Reza Bahrami Serkan Oktay Fatih Aksu F. Betül Yılmaz Güler Ş. Hakan Atapek	*Kocaeli University*	The Effect Of Cryogenic Cooling And Cold Deformation On Microstructural Features Of Solution Annealed Cuni 3 Sicr Alloy
Tuba Terbıyık Kurt Ibrahim Tan	*Çukurova University*	Species Distribution Of Cladocerans In The Seferihisar- Akarca Bay (Aegean Sea)
Tuba Terbıyık Kurt	*Çukurova University*	Recent Sampling Techniques And Analytical Approaches In Marine Zooplankton Research
Ivan Pavlovic	*Scientific Institute of Veterinary Medicine of Serbia*	Polution Of Small Parks In The Urban Area With Dog Parasites
Zeba Ali Mumtaj Mohd Arsh Khan Saimah Khan	*Integral University*	Constructed Wetlands as Eco-Technologies for Decentralized Wastewater Management
Oluwaseun Adekoya Adelaja Babafemi Raphael. Babaniyi Daniel Udorah Babatola J.O.	*Federal University of Technology Akure*	Improvement of Polypropylene (PP)-Chitosan Nanoparticles (CNP) For Advanced Bio-Composite
Olumuyiwa O. Akanbi Ephesus O. Fatunmbi	*Federal Polytechnic, Ilaro, Nigeria*	Flow and Heat Transport Analysis of an Unsteady Magneto-micropolar Nanofluid over a Convectively Heated Porous Expanding Surface
Y. Sarayu Reddy Lalitha Ramachandran	*R.M.K. Engineering College Thiruvallur, India*	Machine Learning Models: The Mathematical Power of Matrix Diagonalization and Quadratic Forms

03.05.2025
Prague Local Time: 14:00-16:00
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SESSION-3, HALL-3 / OTURUM-3, SALON-3

MODERATOR: Nihan Arabacı

Meeting ID: 844 6001 0824
Passcode: 030405

AUTHOR	AFFILITION	ABSTRACT TITLE
Volkan Saritunç Selin Ertürk Gürkan	*Çanakkale Onsekiz Mart University*	Assessment Of Acute Oxidative Responses In Mediterranean Mussel (Mytilus Galloprovincialis) To Graphene Oxide Exposure And Potential Response Modulation By Spinel Zinc Ferrite ($ZnFe_2O_4$)
Nihan Arabacı	*Çukurova University*	Novel Pullulanase Type I Of Bacterial Origin As Detergent Additive
Kadir Aydin Hayrunisa Işbilen	*Trakya Üniversitesi*	Aerodynamic Performance Enhancement Of The Naca 6412 Airfoil Using Plain Flap And Slotted Flap Configurations
Volodymyr Sulyma Glib Astakhov	*Dnipro State Medical University*	Modern Method Of Differential Diagnosis Of Biological Tissues
Wahiba Nesrine Bouzitouna Wahid Oudad	*Belhadj Bouchaib University*	Toward Sustainable Crack Repair: Elastoplastic Study of Hybrid Techniques for Aluminum Structures
Djebbar Noureddine Oudad Wahid Belhamiani Mohamed Boutabout Benali Boulenouar Rachid	*Belhadj Bouchaib University of Ain Temouchent*	Finite Element Analysis Of Stress Distribution In Bone During Insertion Of Different Dental Implant Thread Designs
Sai Janavi P H S. Gnanasree Saranya V Thejaswinie A P T. Chiru Hasini Lalitha Ramachandran	*R.M.K Engineering College Thiruvallur, India*	Volume and Surface Area Calculations for 3D-Printed Structures
Suji S ShanmugaPriya V Lalitha Ramachandran	*R.M.K. Engineering college Thiruvallur*	Jacobian in Robotics: Motion Planning and control

03.05.2025
Prague Local Time: 14:00-16:00
Ankara Local Time: 15:00-17:00

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SESSION-3, HALL-4 / OTURUM-3, SALON-4

MODERATOR: Burhan Yılmaz

Meeting ID: 844 6001 0824
Passcode: 030405

AUTHOR	AFFILITION	ABSTRACT TITLE
Burhan Yılmaz Niyazi Özdemir	*Hakkari University*	Coating Of The Surface Of Porous Niti Implant Produced By Shs Method With Nanostructured Hydroxyapatite Based Bioceramic
Sumayya Akram Matloob Ahmad Sana Aslam Muhammad Zubair	*Government College University*	Furopyridine: It's Synthesis, Chemical Transformations and Biological Applications
Seda Şahin Hülya Torun	*Düzce University*	The Effect Of Salt Stress On Germination Physiology Of Some Sorghum (Sorghum bicolor L.) Varieties
Rachid Hadj Boulenouar Benali Boutabout Noureddine Djebbar	*Djilali Liabes University*	Role Of The Support Patch In Modifying Stress Distribution
Benali Boutabout Ali Djenaoui Noureddine Djebbar Ali Benouis	*Djillali Liabes University*	Effect Of Different Parameters On Stress Levels In Bone Cement Used In Total Hip Arthroplasty
Eshita Gupta Ruchi Jain Garg	*Sharda University*	Metaverse Marketing: New Strategies For Customer Engagement
Sadhana K Rudhrasree S Samreen F Ulsa Deevenamma Sandhya M Lalitha Ramachandran	*R.M.K. Engineering College Thiruvallur, India*	Use Of Multiple Integrals In Astrophysics And Celestial Mechanics
Brahim Ennasraoui Mohamed Rhaya Rahime Eshaghi Malekshah Hassan Ouachtak Amane Jada Abdelaziz Ait Addi	*Ibn Zohr University*	Improved Solar-Powered Photocatalytic Breakdown of Ciprofloxacin Antibiotic and Orange G Dye Using Novel g-C_3N_4/BiOCl/Ag_2MoO_4 Nanocomposite Materials

03.05.2025
Prague Local Time: 14:00-16:00
Ankara Local Time: 15:00-17:00

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SESSION-3, HALL-5 / OTURUM-3, SALON-5

MODERATOR: Ömer Sözen

Meeting ID: 844 6001 0824
Passcode: 030405

AUTHOR	AFFILITION	ABSTRACT TITLE
Tolga Karaköy Ömer Sözen	*Sivas University of Science and Technology*	Yeşil Mercimek Çeşitlerinde Verim Öğeleri Arasindaki İlişkilerin Belirlenmesi Üzerine Bir Araştirma
Ömer Sözen Tolga Karaköy	*Sivas University of Science and Technology*	Bazi Mercimek Çeşitlerinin Agro-Morfolojik Özelliklerinin Ortaya Konulması
Sena Eren Feride N. Türk Hasan Arslanoğlu	*Canakkale Onsekiz Mart University*	Evaluation Of Salix Babylonica Wastes As Ion Exchangers And Raw Materials For Activated Carbon: Investigation Of Methylene Blue Removal From Aqueous Solutions
Yunus Emre Çaygöz	*Cumhuriyet University*	The Effects Of Green Economy On The Agricultural Sector
Vijayakumaran. J K.Sujatha N. Kavitha N.P.G. Bhavani	*M.G.R. Educational and Research Institute*	Reinforced Neural Networks For Lung Cancer Detection
Halliru Sani Musbahu Salisu	*AlQalam University Katsina*	Impact Of Big Data Analytics On The Telecommunication Industry
Thejas kumar. K Shobana. A Sujatha. K, N.P.G. Bhavani Tatireddy Omsai Reddy	*M.G.R. Educational and Research Institute*	Iot For Smart City Management System Services In Network Enabled Applications
D. I. Tarungwa A. A Mann L.A Fadipe S.I Iyen	*Federal University of Technology*	Sustainable Alternative For Textile Coloration Using Phenolic Contents From Differents Combination Of Eucalyptus Camldulensis And Cinnamomum Verum
Lamia Berkane Mohammed Sadok Derki Manel Azzi Chikha Maria	*University of El Oued*	Eco-friendly Synthesis and Biomedical Evaluation of Zinc Oxide Nanoparticles Derived from Moringa oleifera Leaf Extract

04.05.2025
Prague Local Time: 09:00-11:00
Ankara Local Time: 10:00-12:00

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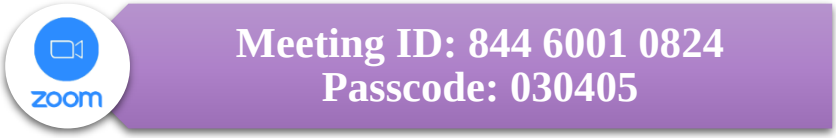
SESSION-1, HALL-1 / OTURUM-1, SALON-1

MODERATOR: Talha Mashhood



AUTHOR	AFFILITION	ABSTRACT TITLE
Talha Mashhood Shehar Bano	*Government College University Faisalabad*	Preparation And Biological Screening Of Hydrazones Using Isolated Cholic Acid
Shehar Bano Talha Mashhood	*Government College University Faisalabad*	Synthesis And Biological Evaluation Of Amides Using Coumarin-3- Carboxylic Acid
Rajaa Diany Mohammed Salah Abdessamad Tounsi	*Sultan Moulay Slimane University*	Phenylazonaphthalene-Based Azo Dyes Are Modified Chemically To Enhance Their Photovoltaic Qualities For Use In Dsscs. Dft And Td-Dft Analysis
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Mehmet Aziz Anik Hasan Dalgiç Serdar Karadaş Ercan Ceyhan	*Selçuk University*	The Course of Cowpea Cultivation in Türkiye: Area, Production, and Yield
Halima HAJJI Mohamed Ouabane Tahar Lakhlifi Mohammed Bouachrine Mohammed Aziz Ajana	*Moulay Ismail University*	In Silico Study Of Novel Molecules With Anticonvulsant Potential Targeting The Gaba A Receptor
Atta ul Haq Hafiz Muhammad Abubakar	*Government College University Faisalabad*	Nickel oxide nanoparticles grafted on graphene oxide (NiO/GO) as photocatalyst for the degradation of Clothianidin under sunlight irradiation

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SESSION-1, HALL-2 / OTURUM-1, SALON-2

MODERATOR: Stanislava Stateva

Meeting ID: 844 6001 0824
Passcode: 030405

AUTHOR	AFFILITION	ABSTRACT TITLE
Stanislava Stateva	*Institute of Plant Genetic Resources*	Development Of Technology For In Vitro Propagation And Storage Of Atropa Belladonna L.
Ahmed Boucherdoud Abdelkarim Seghier Meriem Bendjelloul Benaouda Bestani	*University of Ahmed Zabana*	Design And Optimization Of Polyaniline-Copper Oxide Nanocomposites For Sustainable Wastewater Treatment
Oudad Wahid Noureddine Djebbar Belhamiani Mohamed Bouzitouna Wahiba Nesrine	*University of Ain Témouchent Belhadj Bouchaib*	Numerical Study Of Elliptical Cracks In Pipeline With A Thickness Transition
Abdullah Ahidur Rahman Ashraful Islam Shariful Haque	*Pabna University of Science and Technology*	Phytochemical Screening And Investigation Of Antioxidant, Antibacterial Activity Of Crude Methanolic Extracts Of Litchi Sinensis (Deshi) Fruit Pericarp
M'barka El Mouedden Jamal Mabrouki Driss Azdem Souad El Hajjaji	*Mohammed V University in Rabat*	Ai-Powered Precision Irrigation For Sustainable Agriculture: Enhancing Water Use Efficiency Through Intelligent Systems
Naveen R.A Niranjan K Anandh V Krishnamurthi V HariKishore A	*R.M.K Engineering College*	Engineering And Architecture
Rania Rahmani Amel Ait Meddour Mohammed Benhoula Samia Hamma-Faradji Kahina Belbachir Sylia Terki	*Rania Rahmani University of Bejaia*	Isolation And Characterization Of Newly Identified Lactiplantibacillus Plantarum Probiotic Strains
Haseeba Farrukh Wafa Majeed Ayesha Muhammad Saad Tariq	*University of Agriculture*	Cordia Sinesisameliorates Diabetes Associated Dyslipidemia In Stz Induced Diabetic Rats
Opshora Islam Tondra Md. Ehsanul Haque Chowdhury	*University of Dhaka*	Climatic Influences On Sexual And Reproductive Health: Assessing The Patterns Of Urinary Tract Infections Among Women And Adolescents In Kamrangirchar, Dhaka

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SESSION-1, HALL-3 / OTURUM-1, SALON-3

MODERATOR: Zakia Hammou

Meeting ID: 844 6001 0824
Passcode: 030405

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Halliru Sani Musbahu Salisu	*AlQalam University Katsina*	Impact Of Big Data Analytics On The Telecommunication Industry
J.Salai Thillai Thilagam B.Siva Reddy P.C.Praveen Kumar L.L.Prasanna Kumar	*G.Pulla Reddy Engineering College*	Microstrip Antenna Design For Biomedical Applications
Sabi'u Shitu Muhammad Bature Auwalu Adamu Abubakar	*Ahmadu Bello University*	Microbial Quality Assessment Of Traditional Rice And Groundnut Puddy In Kaduna Metropolis
Zakia Hammou Zakia Guezzen Zouaoui Sereir Yamna Hammou	*University of Science and Technology of Oran*	Reinforcement Shapes And Distribution Influence On Fgm Resonance
Mehedi Hasan Faruq Yeasin Arafat Babu Arnab Goswami Pijush Kanti Jhan Amena Khatun Mahmudul Hasan Shanto Tofazzal Islam Jong-In Park Mehede Hassan Rubel	*Noakhali Science and Technology University*	Molecular Detection Of An Emerging Clubroot Pathogen Plasmodiophora Brassicae From Mustard Plant (Brassica Spp.)
Hafsa Naeem Arif Gull Ayesha Batool Rimsha Anwar Zainab Fatima	*University of Agriculture*	Flowing Into The Future: Innovations For Water Security And Sustainability
Sehrish Firyal Hira Anwar	*University of Veterinary and Animal Sciences*	Molecular Investigation Of Single Nucleotide Polymorphism In Complement Component 5 Gene For Mastitis In Neli Ravi Buffalo
Shalu A.K. Yadav	*Central University of Haryana*	A Novel Elliptic Curve-Driven Pixel Scrambling Technique For Strengthening Ptft Based Image Encryption
Akshaya.B Nethra.P Kavinaya.S	*R.M.K Group Of Institutions*	Laplace Transforms
Majekodunmi Racheal Adedayo	*Kwara State University*	Effect Of Solid- State Fungal Fermentation On The Bioactive Substances In The Pod Of Albizia Lebbeck

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SESSION-1, HALL-4 / OTURUM-1, SALON-4

MODERATOR: Imene Boulhaia

Meeting ID: 844 6001 0824
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Uzma Afzal Aqsa Kanwal Muhammad Zubair Nasir Rasool	*Government College University Faisalabad*	Synthesis, Hydrolysis, And Cox-2/15-Lox Inhibitory Potential Of 4-Acetamidophenyl 4-Bromobenzoate Derivatives
D. I. Tarungwa A. A Mann L.A Fadipe S.I Iyen	*Federal University Of Technology*	Sustainable Alternative For Textile Coloration Using Phenolic Contents From Differents Combination Of Eucalyptus Camldulensis And Cinnamomum Verum
Imene Boulhaia Manuel Bañobre-López Nadji Moulai-Mostefa	*University Of Blida 1 Route De Soumaa*	Thermal Properties Of Ferrogels Based On Agar Gum And Octenyl Succinic Anhydride (Osa) Starch
A. Ait Lhaj B. Ouazik S. Tastift M. El Hasnaoui T. Ait-Taleb H. Chaib	*Ibn Tofail University*	Investigation Of The Optical Properties Of Sno_2 Using Dft With Hubbard Corrections
Hasan Ali Sanjay Das Subrata Roy	*Gopalganj Science And Technology University*	A Computational Study For Structural Modeling And Functional Annotation Of An Uncharacterized Protein From Xanthomonas Oryzae Pv. Oryzae Involved In Photorespiration
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Chokri Bayoudh Malek Ben Ali Afifa Majdoub Taoufik Bettaieb	*Regional Research Centre On Horticulture And Organic Agriculture*	Study Of In Vitro Propagation And Selection For Salt Tolerance Of Local Opuntia Cactus
Ayinde, A. M. Anthony, S. C. Adenipekun, E. A. Belgore, A. K. Umar, O. M.	*University Of Abuja*	Transformation Algorithm For Solving Linear Ordinary Differential Equation Into Integral Equations Using Boubakar Polynomials

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SESSION-1, HALL-5 / OTURUM-1, SALON-5

MODERATOR: Boughedir Nadia

Meeting ID: 844 6001 0824
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AUTHOR	AFFILITION	ABSTRACT TITLE
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Abdul Ali Bhuiyan Mourad A. M. Aboul-Soud Shariful Haque	*Pabna University Of Science And Technology*	A Comprehensive In Vitro And Computational Assessment Of Biological Activities Of Phytoconstituents In Endophytic Bacterial Crude Extract Derived From The Leaves Of Enhydra Fluctuans
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Hamza Benaali Hmad Fatihi Abdellah Tahiri Mohamed Naji	*Sidi Mohamed Ben Abdellah University*	Exploring Novel Simple Hydride Perovskites For Hydrogen Storage Using First-Principles Calculations
Arpita Baidya Prasenjit Paul Pradip Tripura	*Dhamma Dipa International Buddhist University*	Advancing Climate-Resilient Agriculture: Crop Improvement, Biotechnology, And Sustainable Farming For Food Security
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Hanzla Abdullah Syed Ali Raza Naqvi Sadaf Ul Hassan Tania Jabbar Nadeem Ahmad Lodhi Kiran Zeb Areeba Aisha Rafique	*Government College University Faisalabad*	Nanocomposite Hydrogels: Fabrication, Characterization And Biomedical Screening Studies
K.Pooja M.K Vijayalakshmi	*Bharath Institute of Higher education and research*	Review on Immunization and vaccine
Geeti Farahmand Melike Işgören Mesut Sezer Sevil Veli	*Kocaeli University*	A Review On The Treatment Of Laundry Wastewater Using Conventional And Advanced Treatment Methods

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ABSTRACT

NOVEL 1,2,4-TRIAZOLE-DERIVED SCHIFF BASE DERIVATIVES: DESIGN, SYNTHESIS, AND MULTI-ENZYME TARGETING POTENTIAL FOR THERAPEUTIC APPLICATIONS

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ABSTRACT

In this study, a series of novel Schiff base derivatives containing a 1,2,4-triazole core were synthesized and thoroughly characterized using FT-IR, ^{1}H NMR, ^{13}C NMR, ^{19}F NMR, mass spectrometry, and elemental analysis. Their biological activity was evaluated in vitro against human carbonic anhydrase (hCA) isozymes I and II, as well as acetylcholinesterase (AChE) and butyrylcholinesterase (BChE), enzymes that play crucial roles in neurodegenerative and metabolic disorders. The findings revealed that compounds 5a and 5c exhibited potent inhibitory effects against AChE and BChE, suggesting potential applications in neurodegenerative disease treatment. Additionally, 5f and 5g displayed strong inhibition of hCA I and II, indicating their potential as selective inhibitors for metabolic disorders. Molecular docking and molecular dynamics simulations further confirmed that these compounds interact effectively and stably with enzyme active sites, reinforcing their therapeutic potential. Moreover, ADMET profiling demonstrated favorable pharmacokinetic properties, supporting their suitability as drug candidates. Notably, compound 5c showed the highest selectivity for AChE over BChE, making it a promising lead for Alzheimer's disease research. Compared to clinically used inhibitors, several of these compounds exhibited superior inhibitory activity, highlighting their potential in multi-enzyme targeting strategies. Overall, this study introduces a new class of triazole-based Schiff bases as promising candidates for neurodegenerative and metabolic disorder treatments, offering valuable insights for future drug development.
Keywords: 1,2,4-Triazole, Schiff bases, enzyme inhibition, molecular docking, molecular dynamics simulations, ADMET analysis.

NEXT-GENERATION VACCINES AND IN SILICO ANALYSES: A NEW ERA IN IMMUNIZATION

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ABSTRACT
Recent advances in vaccine technology have paved the way for next-generation vaccines that offer enhanced efficacy, safety, and adaptability. Unlike conventional vaccines, these novel approaches leverage cutting-edge techniques such as mRNA-based platforms, viral vector vaccines, and nanoparticle-based delivery systems. In parallel, computational methods, particularly in silico analyses, have revolutionized vaccine design by enabling precise antigen selection, structural modeling, and immunogenicity prediction. These approaches significantly reduce the time and cost associated with vaccine development while improving target specificity. By integrating artificial intelligence, bioinformatics, and molecular dynamics simulations, in silico tools facilitate epitope mapping, protein-ligand interaction modeling, and optimization of vaccine formulations. This review explores the latest advancements in next-generation vaccines and highlights the pivotal role of in silico analyses in accelerating vaccine research, ensuring rapid responses to emerging infectious diseases, and enhancing global immunization strategies.

BASİT CİNSEL SALDIRI SUÇUNUN TİPİKLİĞİ VE YARGILAMA USULLERİNE DAİR BİR DEĞERLENDİRME

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ÖZET

Cinsel suçlar, tarihi çok eskiye dayanan, tüm toplumlarda ve kültürlerde yıllar boyunca işlenen ve işlenmeye devam edilecek olan suç tipleridir. Bu suç tiplerinin tipikliği, cinsellik olgusu, cinsel davranış tanımları ve bu davranışların suç sınırına ulaşması ise tarih boyunca toplumların kültürlerine göre değişim göstermiş ve gösterecektir. Cinsel saldırı suçu, dünyada ve tüm ülkelerde yaşanan global bir suç tipidir. Ancak suçun mahremiyet alanında gerçekleşme özelliğinden dolayı, günümüzde dahi gizli kaldığından "*siyah rakamlar"* oranı oldukça yüksektir. Türk Ceza Kanunu'nda cinsel saldırı suçu, *"Özel Hükümler"* isimli ikinci kitapta, *"Kişilere Karşı Suçlar"* kısmında *"Cinsel Dokunulmazlığa Karşı Suçlar"* bölümünde 102. maddede düzenlenmiştir. Cinsel saldırı suçu, cinsel davranışlar ile mağdurun vücut dokunulmazlığının ihlal edildiği eylemlerdir. Maddenin ilk fıkrasında suçun temel hali düzenlenmiştir.6545 sayılı kanun ile yapılan mevzuat değişiklikleri ile suçta sarkıntılık düzeyi madde kapsamına alınarak, suç karşılığı öngörülen yaptırım miktarları önemli oranda arttırılmıştır. Bu çalışmada, cinsel davranış kavramı doktrindeki görüşler çerçevesinde incelenecek, Türk Ceza Kanunu'nda yer alan basit cinsel saldırı suçuna ilişkin düzenlemeler, 765 sayılı TCK, 5237 sayılı TCK ve 6545 sayılı *''TCK ile diğer Kanunlarda Değişiklik Yapılmasına Dair Kanun''*un getirdiği değişikliklerle irdelenerek, suçun maddi, manevi unsuru, suçla korunan hukuki değer, suçun sarkıntılık düzeyinde işlenmesi, eşe karşı işlenmesi, hukuka aykırılık unsuru, özel görünüş şekilleri açıklandıktan sonra, tipiklik yorumu, nitelikli halleri ve soruşturma usullerine dair uygulamada yaşanan sorunlara değinilerek, Yargıtay kararları ve doktrindeki görüşler ışığında belirtilen hususlarda tespitler yapılıp mevzuat değişikliği önerileriyle uygulamaya katkıda bulunulmaya çalışılacaktır.

Anahtar Kelimeler: Cinsel davranış, basit cinsel saldırı suçu, basit cinsel saldırı suçunda soruşturma, hile, rıza

Açıklama: Bu çalışma yazarın İstanbul Aydın Üniversitesinde yaptığı doktora tez çalışmasından üretilmiştir.

AN EVALUATION OF THE TYPICALITY OF THE CRIME OF SIMPLE SEXUAL ASSAULT AND ITS TRIAL PROCEDURES

ABSTRACT

Sexual crimes are offenses with an ancient history, committed throughout the years across all societies and cultures, and will likely continue to be committed in the future. The perception of these crimes, the concept of sexuality, definitions of sexual behavior, and the point at which such behaviors reach the threshold of criminality have varied and will continue to vary depending on the cultural norms of different societies. Sexual assault is a global crime occurring in all countries. However, due to its nature of being committed in private settings, it often remains undisclosed, leading to a high "dark number" rate. In the Turkish Penal Code, sexual assault is regulated under the "Special Provisions" section of the second book, within the "Crimes Against Individuals" category, under the subsection "Crimes Against Sexual Integrity," specifically in Article 102. Sexual assault consists of acts in which the bodily integrity of the victim is violated through sexual behavior. The first paragraph of the article regulates the basic form of the crime. Legislative amendments introduced by Law No. 6545 have incorporated the concept of "molestation" within the scope of the crime, significantly increasing the prescribed penalties. This study examines the concept of sexual behavior within the framework of doctrinal perspectives. It analyzes the regulations regarding simple sexual assault in the Turkish Penal Code, comparing the provisions in the former Penal Code No. 765, the current Penal Code No. 5237, and the amendments introduced by Law No. 6545 on "Amendments to the Turkish Penal Code and Other Laws." The study discusses the material and moral elements of the crime, the legal interests protected by the offense, the offense of molestation, its commission against a spouse, the element of unlawfulness, and its special appearances. Furthermore, it provides an interpretation of the legal typology, examines aggravated forms of the crime and procedural issues encountered in investigations, and offers assessments based on Supreme Court rulings and doctrinal views. Finally, recommendations for legislative amendments are proposed to contribute to legal practice.

Keywords: Sexual behavior, simple sexual assault crime, investigation of simple sexual assault crime, deception, consent.

Explanation: This study was produced from the author's doctoral thesis at Istanbul Aydın University.

YABANCI OTLARIN İNSANSIZ HAVA ARACI İLE ERKEN EVREDE TESPİTİ VE SINIFLANDIRILMASI İÇİN YERLİ NİTELİKLİ YAZILIM GELİŞTİRİLMESİ*

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ÖZET

İklim değişikliğinin kaçınılmaz etkileri ve dünya çapındaki nüfus artışı nedeni ile gıda üretiminin nitelik ve nicelik açısından geliştirilmesi tarımsal faaliyetler üzerinde önemli bir baskı oluşturmaktadır. Bununla birlikte zirai ürün yetiştiriciler çevresel etkilerin de tetiklediği bitki hastalıkları, zararlı ve yabancı ot istilası gibi olumsuzluklar ile mücadele etmek durumundadır. Yabancı otlar ile mücadelede herbisitlerin kullanımı, daha az zaman ve emek istediğinden en yaygın kontrol stratejisi olmaya devam etse de bu kimyasalların çevreye negatif etkileri kaçınılmazdır. Bu nedenle istenmeyen yabancı otların ürün yetiştirme aşamasının erken evresinde tespit edilerek biçme ve toprak işleme gibi yöntemler ile bertaraf edilmesi oldukça önemlidir. Bu çalışmada yüksek kalitede yetiştirilmesi hedeflenen ürünlerle rekabet ederek topraktaki besine, gübreye, suya ve diğer kaynaklara ortak olarak ürünün strese girmesine neden olan yabancı otların erken evrede tespiti ve sınıflandırılması hedeflenmiştir. Bu doğrultuda ürün yetiştirme aşamasının erken evresinde uçuş yüksekliği, uçuş süresi vb. gibi çeşitli parametreler dikkate alınarak insansız hava aracı (İHA) ile eş zamanlı görüntüler elde edilmiştir. Görüntüler uygun boyutlarda bölütlenerek yapay zekâ temelli derin öğrenme metotları ile çalışma kapsamında geliştirilen yazılıma işlenmiştir. Çalışmanın sonucunda hedef ürünün yetiştirilmesi sırasında toprağı istila eden farklı yabancı (yabani) otların İHA ile tespiti %90 üzerinde bir başarı ile gerçekleştirilmiştir. Termal ve multispektral kamera ile desteklenen görüntüler sayesinde çevresel etkiler, ürünün bitki sağlığı ve besin parametreleri takip edilmiştir. Bunlara ek olarak elde edilen tüm verilerin kullanıcı (çiftçiler, belediyeler, özel sektör vb.) ile paylaşımının dinamik olarak sağlanması amacı ile yerli nitelikli bir web sayfası ve mobil uygulama tasarlanmıştır.

Anahtar Kelimeler: Derin öğrenme, İnsansız Hava Aracı, Herbisit, Sınıflandırma, Sürdürülebilir Çevre ve Tarım, İstilacı Yabancı Ot

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EARLY-STAGE WEED DETECTION AND CLASSIFICATION FROM UAV IMAGERY USING A LOCAL-ORIGIN SOFTWARE SYSTEM*

ABSTRACT

Due to the inevitable effects of climate change and worldwide population growth, improving the quality and quantity of food production creates significant pressure on agricultural activities. In parallel, crop producers are being kept challenged by plant diseases, pests, and invasive weed species. Although herbicide approach remains the most common strategy in weed control due to its convenience and reduced labour demands, the negative environmental consequences of such chemicals are undeniable. Therefore, detecting and eliminating unwanted weed species during the early stages of crop growth has become increasingly important. In this study, the early-stage detection and classification of weed species that compete with high-quality crops for essential resources such as nutrients, fertilizers, and water which ultimately cause plant stress was targeted. In this regard, simultaneous images were obtained with an unmanned aerial vehicle (UAV) by considering various parameters such as flight altitude, flight duration, etc. in the early stages of the crop cultivation phase. These images were segmented into appropriate sizes and processed using a novel local-origin software system that incorporates artificial intelligence and deep learning-based methods. As a result, the UAV-assisted detection of invasive weed species infesting the soil during crop growth was successfully achieved with accuracy over 90%. Additionally, thermal and multispectral imagery supported the monitoring of environmental influences, plant health, and nutrient parameters. Furthermore, to enable dynamic sharing of all collected data with end users such as farmers, municipalities, and private sector stakeholders, web platform and mobile application were developed with local origin.

Keywords: Deep Learning, Unmanned Aerial Vehicle, Herbicide, Classification, Sustainable Environment and Agriculture, Invasive Weed Species.

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BAMYA GAMI İÇERİKLİ AKILLI HİDROJEL SENTEZİ

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ÖZET
Bu çalışmada, bamya meyvesi atıklarından elde edilen bamya zamkları, zayıf karboksi asitler içeren pH'a duyarlı hidrojeller hazırlamak için kullanılmıştır. Atık yönetimi hem çevre hem de ekonomi açısından önemli bir konudur. Bu bağlamda, atıkların çeşitli alanlarda değerlendirilmesi için hidrojel haline getirmek, birçok kullanım senaryosu için yararlı olabilir. Doğal atık polimerik ürünler ve polimerik malzemeler kullanmak, sentetik polimerlere kıyasla zorlayıcı ve daha düşük şişme özelliklerine sahip olabilir. Bu çalışmada, bu kısıtlamaların üstesinden gelmek ve sentezlenen hidrojellerin şişme değerlerini geliştirmek için çeşitli sentetik biyopolimerler kullanılmıştır. Bu şekilde, hazırlanan iç içe geçen polimer ağı ile daha iyi şişme yeteneğine sahip, iyi bir bağlanma elde edilen polimerik hidrojeller elde edilebilir. Sonuçlar, hidrojel sentez sürecinde zamk oranının çözeltinin akışkanlığını çok düşük olacak şekilde değiştirebilen ve reaksiyon çözeltisindeki moleküler hareketi sınırlayarak daha az şişme özelliğine yol açabilen önemli bir parametre olduğunu göstermiştir. pH'a duyarlı zayıf karboksi asit (R-COOH) derişimi de daha yüksek derişimlerin reaksiyon çözeltisindeki monomerlerin polimerizasyonuna müdahale edebilen polimerik çözeltinin pH'ını düşürebilmesi nedeniyle önemlidir. Bu sonuçlar polimerizasyon reaksiyon çözeltisindeki bileşenlerin derişimlerinin son ürününün niteliği açısından belirleyici olabilecek kadar önemli olduğunu göstermiştir.

Anahtar Kelimeler: Bamya gamı, Hidrojel, Birbirine nüfuz eden polimer ağı, Polimerleşme

SYNTHESIS OF OKRA GUM-BASED SMART HYDROGEL

ABSTRACT

In this study, okra gums obtained from okra fruit wastes were used for preparing pH responsive hydrogels that contain weak carboxyl acids. Waste management is an important topic for both environmental and economics. In this regard, using waste into a hydrogel that can be used in various fields can be useful for many usage scenarios. Using natural waste polymeric byproducts and polymeric materials can be compelling and lower swelling properties compared to synthetic polymers. In this study, to overcome these features and further improve the hydrogels for better properties, several synthetic biopolymers were added. This way, a good bond with better swell-ability can be achieved with the prepared interpenetrating polymer network. The results showed that the gum ratio is an important parameter in the hydrogel synthesis process, which can change the fluidity of the solution to be too low and limit the molecular motion in the reaction solution, leading to less swelling property. pH responsive weak carboxyl acids (R-COOH) concentration is also crucial because higher ratios can lower the pH of the polymeric solution that can interfere with the polymerization of the monomers in the reaction solution. These results showed that the concentrations in the polymerization reaction solution are essential that can be decisive to the end-product.

Keywords: Okra Gum, Hydrogel, Interpenetrating Polymer Network, Polymerization

HEAT TRANSFER AND ENERGY ANALYSIS OF AN INDUSTRIAL IRONING MACHINE

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ABSTRACT
In this study, energy, heat transfer, and fluid flow analyses were performed for an industrial roller ironer. These machines dry and press textiles by passing them between a rotating roller and a stationary heated chest. Thermal oil circulates within the chest, providing a high and uniform surface temperature to evaporate moisture and smooth the fabric. This system is widely used in industrial laundries for efficient, high-speed ironing of fabrics. In this context, Conjugate Heat Transfer CFD simulations were carried out for two scenarios: one with pre-dried fabric and one without. The simulations were validated using temperature measurements taken directly from the machine. As a result, the surface heat load and temperature distribution were obtained, and regions with low heat flux were identified. These areas were shown to result from complex three-dimensional separated flow in the U-turns of the oil channels, which limits effective heat transfer to those spots. Design improvements were proposed for these regions. Overall, the results indicate a generally uniform ironing performance across the ironing surface.
Keywords: Heat transfer, Energy analysis, CHT, CFD, Industrial Ironer, Thermal Oil Heated Flatwork Ironer.

HETEROGENEOUS FENTON-LIKE DEGRADATION OF TETRACYCLINE BY SBA-15/Fe-Co NPs COMPOSITE MATERIAL SYNTHESIZED USING BLACK MULBERRY (*Morus nigra L.)* LEAVES EXTRACT

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ABSTRACT

In this study, SBA-15 supported iron-cobalt bimetallic nanoparticles (SBA-15/Fe-CoNPs) composite material was green synthesized by using a cost-effective reducing agent, black mulberry (*Morus nigra L.*) leaves aqueous extract. The composite material was utilized as a heterogeneous Fenton-like catalyst for the effective degradation of tetracycline antibiotics. Characterizations were performed by FT-IR, XRD, SEM-EDX, and BET analyses. The characterization studies demonstrated that SBA-15 and SBA-15/Fe-CoNPs were synthesized successfully. According to SEM images, the morphology of SBA-15 was spherical. The Fe-Co NPs consist of agglomerated spherical nanoparticles, and they were dispersed on the surface of SBA-15. The BET surface areas of SBA-15 and SBA-15/Fe-Co NPs were 734.79 and 428.45 m^2/g, respectively. The effects of Fenton-like reaction parameters such as initial pH of the solution (3.0 – 11.0), initial tetracycline concentration (50 – 200 ppm), catalyst concentration (0.5 – 3.0 g/L), oxidant (H_2O_2) concentration (10 – 1000 mM), contact time (0 – 180 min), and temperature (25°C – 45°C) were investigated. The optimum conditions of initial pH, initial tetracycline concentration, catalyst, and H_2O_2 concentrations, contact time, and temperature were determined to be 3.0, 100 ppm, 1.0 g/L, 250 mM, 180 min, and 45°C respectively. Under these conditions, 92.05 % degradation efficiency was achieved for 200 ppm tetracycline. The kinetics and thermodynamic parameters of the reaction were determined. The reaction order was determined to be of the second order. The reaction rate constants were determined as k = 0.00007 L/mol. min, k= 0.0008 L/mol.min, and k= 0.003 L/mol.min for T=25°C, T=35°C, and T=45°C, respectively. The activation energy (E_a) was found as 148.45 $kJ.mol^{-1}$; the $\Delta H^{\#}$ and $\Delta S^{\#}$ values were calculated as 145.9 $kJ.mol^{-1}$ and 357.91 $J.mol^{-1}.K^{-1}$, respectively.

Keywords: Fenton-like degradation, Heterogeneous catalyst, Tetracycline, SBA-15, Bimetallic nanoparticles, Green synthesis

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THERMAL, CRYSTALLOGRAPHIC, AND MORPHOLOGICAL ANALYSIS OF MARBLE POWDER AND KAOLIN REINFORCED HYBRID COMPOSITES

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ABSTARCT
In this study, the thermal, crystallographic, and morphological properties of polypropylene (PP)-based composites containing marble powder and kaolin were investigated. The aim was to evaluate the effects of these fillers on the composite's overall performance and potential engineering applications. Thermogravimetric Analysis (TGA) results showed that adding marble powder and kaolin improved the thermal stability of PP composites by increasing the degradation onset temperature. Differential Scanning Calorimetry (DSC) analyses revealed that the crystallization temperature varied with filler content. Marble powder increased the crystallization temperature, while kaolin slightly modified the crystallization behavior. These findings suggest that the fillers affect the nucleation and crystallization kinetics of PP. X-ray Diffraction (XRD) analyses confirmed changes in the crystal structure of the composites, showing the successful integration of marble powder and kaolin into the PP matrix. Characteristic peaks of both fillers were observed, indicating their influence on the composite's structural properties. Scanning Electron Microscopy (SEM) examinations provided insights into the surface morphology. The SEM images revealed a more uniform distribution of filler particles in hybrid composites, reducing agglomeration and enhancing structural integrity. Overall, the results demonstrated that marble powder and kaolin-reinforced hybrid composites exhibit improved thermal stability, induce structural changes in the crystalline phase, and enhance surface morphology. These enhancements suggest that such composites could be effectively used in engineering applications requiring high thermal resistance and mechanical stability.
Keywords: Marble, Kaolin, Polymer Composite, Thermal Properties

MECHANICAL AND VISCOELASTIC PROPERTIES OF MARBLE POWDER FILLED POLYPROPYLENE COMPOSITES

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ABSTRACT
The mechanical and viscoelastic characteristics of marble powder filled polypropylene (PP) composites were examined in this study. The main objective is to evaluate the effect of using marble powder as a filler on the strength, modulus and viscoelastic behavior of PP composites. Composites were produced using different weight percentages of marble powder (5%, 10%, 15% and 20%) and tested for tensile, flexural and dynamic mechanical properties. The addition of marble powder had a significant impact on the mechanical performance of PP, according to tensile and flexural tests. As the filler content increased, the tensile strength slightly decreased, mostly as a result of decreased interfacial adhesion between the polymer and the filler. However, the increased stiffness of the composite structure was demonstrated by improvements in flexural strength and elastic modulus. The best balance between strength and stiffness was observed at 10% marble powder content. Dynamic Mechanical Analysis (DMA) was conducted to assess the viscoelastic behavior of the composites. The results showed an increase in storage modulus (E') with higher marble powder content, confirming enhanced stiffness and load-bearing capacity. Additionally, the loss modulus (E") and tan delta (damping factor) values indicated improved energy dissipation, particularly at lower frequencies. Overall, the incorporation of marble powder enhanced the stiffness and viscoelastic performance of PP-based composites while slightly reducing tensile strength. These findings suggest that marble powder-reinforced PP composites could be effectively utilized in applications requiring improved rigidity and thermal stability, such as construction materials and automotive components.
Keywords: Marble Powder, Polymer Composite, Mechanical Propertie

AN EVENT-BASED TRAFFIC MANAGEMENT APPLICATION IN VANETS

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ABSTRACT
Vehicular AdHoc Networks (VANETs), an important sub-branch of intelligent transportation systems (ITS), have become quite interesting in both academia and industry in recent years. Thanks to the wireless communication between vehicles and roadside units, important traffic-related information is shared in VANETs, and thus, safety, management and infotainment applications can be implemented. In VANET event-based traffic management systems, vehicles that witness an event on the route broadcast an event status message to their neighbours in order to warn them. The vehicles receiving this message wait for a decision until their distance to the event falls below a certain threshold and make a one-time decision depending on the messages they receive. With the decision made, it is aimed for the vehicles to take precautions without having to witness the event, thus preventing traffic congestion and reaching their destinations earlier. In this study, an accident event is created at the midpoint of two consecutive lanes on a 4-lane highway scenario using the simulation method, and the vehicles that witnessed the accident are made to stop and broadcast an incident report around them. In this way, it is aimed for the vehicles that have not witnessed the incident to take early precautions by changeing their lanes to prevent waiting due to traffic congestion. The performance of the proposed traffic management system with messaging content is compared with the classical traffic scenario without messaging, in terms of the time for the vehicles to reach the destination, the number of vehicles that stop during journey, and their stopping times. In addition, the effect of the decision distance of the vehicles is examined. It is thought that the obtained results will shed light on future event-based traffic management scenarios and trust-based communication systems.
Keywords: traffic management, event messaging, simulation, VANET.

VISCOELASTIC AND THERMAL PERFORMANCE OF 3D-PRINTED SiO_2 NANOCOMPOSITES: INFLUENCE OF SILANE MODIFICATION ON REINFORCEMENT EFFICIENCY

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ABSTRACT
Additive manufacturing technology is widely used in many fields such as aerospace, biomedical, automotive and engineering, allowing structures with complex geometries to be fabricated precisely and efficiently. Among these production methods, resin-based three-dimensional (3D) printing technologies, digital light processing (DLP) and stereolithography (SLA), are based on the principle of ultraviolet-light (UV-light) curing of photopolymer resins. Inorganic fillers are incorporated to improve the mechanical, thermal and physical properties of these resins. Although SiO_2 nanoparticles provide advantages in terms of transparency and mechanical strength, they may interact poorly with the matrix and tend to aggregate because their surfaces are not hydrophobic. Modification of the surface of the nanoparticles with silane groups can provide better bonding with the resin matrix and increase mechanical strength and structural integrity. In this study, the effect of silane modification on thermal and viscoelastic properties of SiO_2 reinforced epoxy composites fabricated by additive manufacturing were investigated. In order to determine this effect, the thermal and viscoelastic behavior of the composites was evaluated by thermogravimetric analysis (TGA), thermal conductivity measurement and dynamic mechanical analysis (DMA), respectively. The results obtained showed that silane modification improved the dispersion of nanoparticles and strengthened the interfacial interaction with the polymer matrix. Thus, it was determined that thermal stability increased, the storage modulus improved and the changes in the surface energy affected the overall performance of the composite. This study reveals that silane modification can provide significant improvements in terms of material engineering in nanocomposites fabricated by 3D printing.
Keywords: Additive manufacturing, nanocomposite, silane modification, viscoelastic properties, thermal properties.

THE EFFECTS OF SUPPORT IRRIGATION AND NITROGEN DOSES ON WHEAT YIELD AND YIELD CHARACTERISTICS IN SUMMER WHEAT AT DIFFERENT DEVELOPMENTAL PERIODS

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ABSTRACT
Wheat is important among the factors affecting yield and quality in global food security. This study investigated the effects of different irrigation times and nitrogen doses applied at various growth stages of wheat. In this study, nine different irrigation periods (full irrigation, tillering+flowering, emergence, gestation, spike, flowering, milky maturity, flowering+ripening, and rain) and four different nitrogen doses (8, 12, 16, and 20 kg/ha) were applied. Morphological parameters such as the number of tillers, grain yield, biological yield, plant height, hundred-grain weight, and number of grains in the spike were evaluated, and irrigation and nitrogen doses were compared regarding plant development. The results showed that full irrigation, especially with the highest nitrogen dose (N20), provided the highest values for most parameters examined. This emphasizes the importance of adequate water and nutrient supply throughout the growing season of wheat. These findings suggest that full irrigation and 20 kg/da nitrogen should be applied to maximise wheat yield.
Keywords: Wheat yield, irrigation timing, nitrogen dose, grain yield, morphology

EFFECTS OF DIFFERENT ZEOLITE RATIOS ON SOME SOIL PROPERTIES IN LIGHT AND HEAVY-TEXTURED SOILS

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ABSTRACT

This study aimed to examine the effects of different zeolite doses on specific physicochemical and structural characteristics of soils with light and heavy textures under controlled conditions. The zeolite applied pots were incubated for six months. The effects of applying zeolite at five different doses (0, 2.5, 5, 7.5, and 10%) on the pH, electrical conductivity, organic matter, calcium carbonate, available phosphorus (P_2O_5), mean weight diameter (MWD), water-stable aggregates (WSA), and organic matter (OM) of the soil were assessed. The lowest pH (6.85) and EC (0.30 dS m^{-1}) were found at higher zeolite doses, significantly decreasing soil pH and EC levels in light-textured soils. With zeolite applications, the content of organic matter was statistically unaffected, but the contents of $CaCO_3$ and P_2O_5 dropped dramatically. Significantly, WSA rose, peaking at 43.38% at the 10% dosage, suggesting enhanced aggregate stability. Applying zeolite did not significantly change the pH, EC, OM, or P_2O_5 content of heavy-textured soils. At higher doses, WSA significantly improved, reaching a peak of 77.24% with 2.5% zeolite. These findings imply that zeolite has a more noticeable impact on both soil types' structural stability, especially when it comes to increasing WSA, with varying effects on chemical properties based on texture. These results corroborate earlier research showing that zeolite improves soil physical characteristics and aggregate stability due to its high cation exchange capacity and water retention ability. As a result, zeolite can be regarded as a mineral soil conditioner that works well to enhance soil structure, decrease nutrient leaching, and boost soil erosion resistance.

Keywords: zeolite, soil amendment, soil structure, soil texture

THE EFFECT OF PRINTER PARAMETERS ON FLATNESS IN SAMPLES PRODUCED WITH FDM METHOD

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ABSTRACT
Additive manufacturing technologies are rapidly becoming widespread in industrial production processes. Within this technology, Fused Deposition Modeling (FDM) is one of the most commonly used techniques. FDM operates based on the principle of adding layers of a thermoplastic filament that is melted by a heated printer head. Due to its advantages, such as low cost and fast production process, it is particularly used in many sectors for low-volume production, prototype manufacturing, and design validation. However, this method has some limitations in terms of dimensional and geometric accuracy. Dimensional and geometric accuracy is crucial for the strength and performance of machine parts that work in contact and interaction. This study aims to reveal the effect of printer parameters on geometric tolerances in PLA samples produced by the FDM method. The research was conducted with a 0.4 mm nozzle diameter, three different layer thicknesses, three different infill percentages, and three different temperatures. The produced samples were examined in terms of flatness tolerance, and the effect of the parameters was compared. The best flatness value was obtained with a temperature of 200°C, 100% infill, and a 0.1 mm layer thickness, while the greatest deviation from flatness was observed at a temperature of 240°C, 80% infill, and 0.1 mm layer thickness. Based on the average flatness values, it was observed that the samples produced with a 0.05 mm layer thickness showed 50% better flatness than the other samples. Furthermore, it was determined that the samples produced at 220°C had 58% better flatness than those produced at 240°C and 42% better flatness than those produced at 200°C.
Keywords: Additive Manufacturing, Flatness, Geometric Tolerances, Fused Deposition Modeling

ZAMAN-KESİRLİ NEWELL–WHİTEHEAD–SEGEL DENKLEMİNİN ÇÖZÜMÜ İÇİN KAPALI ÜSTEL BİR ŞEMA

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ÖZET

Doğrusal olmayan kısmi diferansiyel denklemler (NLPDE'ler), özellikle kesirli mertebeden türevler içeren türleri, geniş bir yelpazedeki fiziksel süreçlerin modellenmesinde oldukça etkili araçlar olarak öne çıkmaktadır. Kesirli kısmi diferansiyel denklemler (FPDE'ler), sürekli ortam mekaniği, akışkanlar dinamiği, dalga yayılımı, akustik, elektro-dinamik, sinyal analizi, biyomedikal mühendislik ve plazma fiziği gibi mühendislik ve uygulamalı bilimlerin birçok dalında yaygın olarak karşımıza çıkmaktadır. Bu tür doğrusal olmayan sistemlerin çözümüne yönelik olarak çeşitli analitik ve sayısal yöntemler geliştirilmiştir. Bu yöntemler arasında kesirli alt-denklemler yöntemi, kesirli artık güç serisi yöntemi, değiştirilmiş ayrıştırma yöntemi, (G′/G) genişletme yöntemi, kesirli indirgenmiş diferansiyel dönüşüm yöntemi, Haar dalgacık işlemsel matris yöntemi, değiştirilmiş Kudryashov yöntemi, genelleştirilmiş genişletilmiş tanh-fonksiyon yöntemi ve homotopi analiz yöntemi yer almaktadır. Bu çalışma, iki boyutlu sistemlerde şerit desenlerinin oluşumunu tanımlamak amacıyla sıklıkla kullanılan zaman-kesirli Newell–Whitehead–Segel (NWS) denkleminin sayısal çözümüne odaklanmaktadır. Zaman-kesirli NWS denklemi aşağıdaki biçimde ifade edilir: $D_t^{\alpha} u(x,t) = u_{xx}(x,t) + u(x,t) - u^3(x,t),\ 0 < \alpha \le 1$ Bu çalışmada, uyumlu kesirli türev dikkate alınarak zaman-kesirli Newell–Whitehead–Segel (NWS) denkleminin çözümüne yönelik özel olarak geliştirilmiş kapalı üstel sonlu fark şeması sunulmaktadır. Önerilen sayısal şemanın kararlılığını değerlendirmek amacıyla von Neumann kararlılık analizi kullanılmaktadır. Yöntemin kapalı yapısından dolayı, her bir zaman adımında doğrusal olmayan denklem sistemleri ortaya çıkmakta ve bu sistemler Newton yöntemi ile doğrusal hale getirilerek sayısal olarak çözümlenmektedir. Yöntemin doğruluğunu test etmek amacıyla elde edilen sayısal sonuçlar, bilinen analitik çözümlerle karşılaştırılmıştır. Simülasyon sonuçları, önerilen yöntemin zaman-kesirli NWS denkleminin karmaşık yapısını çözmede doğru ve güvenilir olduğunu göstermektedir.

Anahtar Kelimeler: zaman-kesirli Newell–Whitehead–Segel (NWS) denklemi, örtük üstel sonlu farklar yöntemi, von-Neumann kararlılık analizi.

AN IMPLICIT EXPONENTIAL SCHEME FOR SOLVING THE TIME-FRACTIONAL NEWELL–WHITEHEAD–SEGEL EQUATION

ABSTRACT

Nonlinear partial differential equations (NLPDEs), particularly those involving fractional-order derivatives, have proven to be powerful tools in modeling a broad spectrum of physical processes. Fractional partial differential equations (FPDEs) appear extensively in various branches of engineering and applied sciences, including but not limited to continuum mechanics, fluid dynamics, wave propagation, acoustics, electrodynamics, signal analysis, biomedical engineering, and plasma physics. To address the complexities associated with solving such nonlinear systems, a variety of analytical and numerical approaches have been developed. These include the fractional sub-equation method, the fractional residual power series method, the modified decomposition method, the (G′/G) expansion method, the fractional reduced differential transform method, the Haar wavelet operational matrix method, the modified Kudryashov method, the generalized extended tanh-function method, and the homotopy analysis method.This study is focused on obtaining a numerical solution for the time-fractional Newell–Whitehead–Segel (NWS) equation, a model frequently used to describe the emergence of stripe patterns in two-dimensional systems. The time fractional NWS equation is written as follows: $D_t^{\alpha} u(x,t) = u_{xx}(x,t) + u(x,t) - u^3(x,t)$, $0 < \alpha \leq 1$.In this study, we introduce an implicit exponential finite difference scheme tailored to the solution of the time-fractional Newell–Whitehead–Segel (NWS) equation, considering the conformable fractional derivative. Von Neumann stability analysis is employed to evaluate the stability of the proposed numerical scheme. Due to the implicit nature of the scheme, each temporal iteration leads to a system of nonlinear equations. These systems are linearized using Newton's method, facilitating their numerical resolution. To validate the accuracy of the method, numerical results are benchmarked against known exact solutions. The simulation results show that the proposed method is accurate and reliable for solving the complex structure of the time-fractional NWS equation.

Keywords: time-fractional Newell–Whitehead–Segel (NWS) equation, implicit exponential finite difference method, von-Neumann stability analysis.

SAĞLIK HİZMETLERİ MESLEK YÜKSEKOKULU ÖĞRENCİLERİNİN AŞI VE AŞI REDDİ KONUSUNDA BİLGİ VE TUTUMLARININ DEĞERLENDİRİLMESİ

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ÖZET
Amaç: Bu çalışma sağlık hizmetleri meslek yüksekokulunda okuyan öğrencilerin aşı ve aşı reddi konusunda bilgi ve tutumlarının değerlendirilmesi amacıyla yapılmıştır. Yöntem: Araştırmanın evrenini 2021-2022 eğitim öğretim yılında bir üniversiteye bağlı ilçede bulunan Meslek Yüksekokulunda öğrenim gören öğrenciler oluşturmaktadır. Araştırmaya katılmaya gönüllü 213 öğrenci araştırmanın örneklemini oluşturmuştur. Verilerin toplanmasında araştırmacı tarafından konu ile ilgili literatür taraması yapılarak Sosyo-demografik Bilgi Formu, Aşı Reddi Bilgi ve Tutum Formu oluşturulmuş, oluşturulan form, Google formlar üzerinden oluşturulan araştırma linki dijital ortamda öğrenciler ile paylaşılmış, araştırmaya davet edilmiştir. Araştırmadan elde edilen veriler, araştırmacılar tarafından SPSS 25 (Statistical Programme for Social Sciences) paket programı ile değerlendirilmiş ve istatistiksel analizi; yüzdelik hesabı, ortalama, standart sapma, MANOVA kullanılarak yapılmıştır. Bulgular: Araştırmaya katılan öğrencilerin yaş ortalaması 20,50 bulunmuş, araştırmaya katılan öğrencilerin %83,1'i kadın, %60,6'sı 1.sınıfta, %57,7'si Çocuk Gelişimi programında okumaktadır. Öğrencilerin %72,72'si çocukluk aşılarının çocukların sağlığı için önemli olduğunu, %46,17'si aşıların yararlılığına ilişkin şüpheleri konusunda kararsız olduğunu, %47,08'i çocukları hastalıklardan korumanın en iyi yolunun aşı olmak olduğu, %38,99'u sağlıklı yaşam tarzları ve doğal beslenme uygulanırsa aşılamanın gerekli olmadığı, %26,08'i bazı aşıların önledikleri enfeksiyonlardan daha tehlikeli olduğu, %22,75'i çocuklarına aşı yaptırmayı reddeden ailelerin doğru davrandığını düşündüğünü, %60,66'sı aşılar hakkında olumsuz bilgi aldığı veya duyduğunu ifade etmişlerdir.Sonuç: Çalışma bulgularına göre; geleceğin sağlık personeli ve çocuk gelişimcisi olarak topluma hizmet ve eğitim verecek olan öğrencilerin aşılara yönelik tutumları olumlu gibi görünse de olumsuz tutumlarda azımsanamayacak kadar yüksektir.
Anahtar Kelimeler: Aşı, Aşı Reddi, Öğrenci

EVALUATION OF HEALTH SERVICES VOCATIONAL SCHOOL STUDENTS' KNOWLEDGE AND ATTITUDES ABOUT VACCINATION AND VACCINATION REFUSAL

ABSTARCT

Aim: This study was conducted to evaluate the knowledge and attitudes of students studying at a health services vocational school regarding vaccination and vaccine refusal. Method: The universe of the study consists of students studying at a vocational school affiliated to a university in the district in the 2021-2022 academic year. 213 students who volunteered to participate in the study constituted the sample of the study. In the collection of data, the researcher conducted a literature review on the subject and created a Socio-demographic Information Form, Vaccine Refusal Information and Attitude Form, the created form, the research link created via Google Forms were shared with the students in the digital environment and they were invited to the study. The data obtained from the study were evaluated by the researchers with the SPSS 25 (Statistical Programme for Social Sciences) package program and statistical analysis was performed using percentage calculation, mean, standard deviation, MANOVA.Results: The average age of the students participating in the study was found to be 20.50, 83.1% of the students participating in the study were female, 60.6% were in the first grade, and 57.7% were studying in the Child Development program. 72.72% of the students stated that childhood vaccinations were important for children's health, 46.17% were undecided about their doubts about the usefulness of vaccines, 47.08% stated that the best way to protect children from diseases was to get vaccinated, 38.99% said that vaccination was not necessary if healthy lifestyles and natural nutrition were implemented, 26.08% said that some vaccines were more dangerous than the infections they prevented, 22.75% thought that families who refused to vaccinate their children were acting correctly, and 60.66% received or heard negative information about vaccines.Conclusion: According to the study findings; Although the attitudes of students who will serve and educate society as future health personnel and child development specialists towards vaccines may seem positive, negative attitudes are also considerably high.

Keywords: Vaccine, Vaccine Refusal, Student

ÖZDENETİM FİNANSAL OKURYAZARLIĞI NASIL ETKİLİYOR? ORTAOKUL ÖĞRENCİLERİ ÜZERİNDE KESİTSEL BİR ARAŞTIRMA

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ÖZET
Öz-denetim, finansal okuryazarlığın temel bir unsuru olarak bireylerin finansal planlarına sadık kalma ve ani harcama dürtülerini kontrol etme becerisini doğrudan şekillendirir. Bu özellik, finansal okuryazarlık kapsamında edinilen teorik bilgilerin pratikte uygulanabilmesi için kritik bir köprü işlevi görür. Dürtüsel tüketim alışkanlıklarından kaçınan ve planlı bir bütçe yönetimi benimseyen bireyler, finansal kaynaklarını optimize etme konusunda daha başarılı olurken, aşırı borçlanma gibi risklerden de korunurlar. Bu disiplinli yaklaşım, finansal bilgi birikiminin etkin bir şekilde kullanılmasını sağlayarak bireylerin mali refah düzeyini artırmalarına zemin hazırlar. Bu araştırmanın amacı ortaokul öğrencilerinin finansal okuryazarlık becerileri ile öz-denetim değerleri arasındaki ilişkileri araştırmaktır. İlişkisel tarama modeline göre tasarlanan araştırmanın çalışma grubunu Türkiye'nin güneyinde yer alan Gaziantep ilinin merkezinde öğrenimine devam eden basit seçkisiz örnekleme yoluyla seçilmiş 580 ortaokul öğrencisi oluşturmuştur. Veriler ergenler için finansal okuryazarlık ölçeği ve öz-denetim ölçeği ile toplanmıştır. Verilerin analizinde betimsel istatistikler ve korelasyon analizinden faydalanılmıştır. Bulgular öz-denetim değeri ile finansal okuryazarlık becerileri arasında anlamlı ilişkilerin olduğunu ve öz-denetim değerinin finansal okuryazarlık becerisinin önemli bir yordayıcısı olduğunu ortaya koymuştur. Sonuçlar öz-denetim ve finansal okuryazarlık arasındaki karmaşık ilişkileri ortaya koymuş ve öz-denetimin küçük yaşlarda edinilmesinin birey ve toplum finansal refahı açısından önemli bir etken olduğunu göstermiştir.
Anahtar Kelimeler: Finansal Okuryazarlık, Öz-denetim, Ortaokul Öğrencileri

HOW DOES SELF-CONTROL AFFECT FINANCIAL LITERACY? A CROSS-SECTIONAL STUDY ON MIDDLE SCHOOL STUDENTS

ABSTRACT

As a core element of financial literacy, self-control directly shapes individuals' ability to stick to their financial plans and control sudden spending impulses. This characteristic serves as a critical bridge for the practical application of the theoretical knowledge acquired within the scope of financial literacy. Individuals who avoid impulsive consumption habits and adopt a planned budget management are more successful in optimizing their financial resources and are protected from risks such as excessive borrowing. This disciplined approach paves the way for individuals to increase their financial well-being by effectively using financial knowledge. This study aims to investigate the relationship between financial literacy skills and self-control values of middle school students. The research study group, which was designed according to the relational survey model, consisted of 580 middle school students selected through simple random sampling in the center of Gaziantep province located in the south of Türkiye. Data were collected using the financial literacy scale for adolescents and the self-control scale. Descriptive statistics and correlation analysis were used to analyze the data. The findings revealed significant relationships between self-control and financial literacy skills, and self-control value significantly predicted financial literacy skills. The results revealed the complex relationships between self-control and financial literacy and showed that acquiring self-control at a young age is essential for individual and community financial well-being.

Keywords: Financial Literacy, Self-control, Secondary School Students

ANALYSIS OF r −CIRCULANT MATRICES CONSTRUCTED FROM k −FIBONACCI AND k-LUCAS QUATERNIONS: NORMS AND EIGENVALUE PROPERTIES

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ABSTRACT
Circulant matrices are widely used across numerous fields, including coding theory, statistical design, signal processing, and engineering, owing to their symmetric structure and computational efficiency. Motivated by their extensive applicability, this study focuses on r-circulant matrices whose entries are constructed from k-Fibonacci and k-Lucas quaternions, which are generalized forms of hyper-complex numbers.The research investigates key algebraic and spectral properties of these matrices, including eigenvalues, determinants, Euclidean norms, and spectral norms. In addition, upper and lower bounds for these norms are established, offering insight into their numerical behavior. Special attention is given to the cases $r = 1$ and $r = -1$, corresponding to right and skew-right circulant matrices, respectively.Lastly, the study analyzes the limiting behavior of these norms using Hadamard (element-wise) multiplication of the derived special matrices. The results contribute to a deeper theoretical understanding of quaternion-based circulant matrices and provide a potential foundation for applications in advanced computing and cryptography. Finally, the study explores the limiting behavior of the matrix norms through the use of Hadamard (elementwise) multiplication applied to the specialized matrices developed. This final step aids in understanding the asymptotic properties of these matrices under repeated operations or large-dimensional limits, which is particularly relevant in large-scale data systems or iterative computation frameworks.

Keywords: k-Fibonacci and k-Lucas Quaternion, Norm (Spectral and Euclidean), Eigenvalues, Circulant matrices.
Acknowledgments: This study was supported by the Scientific Research Projects (BAP) Coordination Unit of Sivas Science and Technology University under project number 2025-HDP-MÜH-002.

THE RESPONSES OF BIOMARKERS BELONGING TO DIFFERENT METABOLIC SYSTEMS OF FRESHWATER MUSSELS (*UNIO TIGRIDIS*) FOLLOWING CADMIUM EXPOSURES

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ABSTRACT
Mussels are sedentary organisms that feed by filtering water, making them valuable bioindicators for assessing environmental pollution. In this research, the toxic effects of cadmium were determined in freshwater mussels (*Unio tigridis)* after exposure to different cadmium concentrations (0, 30, 90, 270 µg Cd/L) for 0, 7, 14 and 21 days. After each exposure duration, the responses of various biomarkers belonging to different metabolic systems were analyzed. During the experiments, the mussels were fed with laboratory-cultured algae (*Chlorella vulgaris*). There was no mussel mortality after different cadmium exposures in all durations. However, the responses of biomarkers exhibited significant changes ($p<0.05$) compared to the control group. Cadmium exposure significantly ($p<0.05$) increased the response of the antioxidant enzymes in the digestive glands, as the activities of CAT, SOD, GPX, GST and GR were higher after cadmium exposures compared to controls. Additionally, malondialdehyde levels in the digestive glands increased significantly following exposure, emphasizing lipid peroxidation occurred. However, acetylcholinesterase and Ca-ATPase activities in muscle tissue were significantly decreased. Nevertheless, there was some fluctuations In the osmoregulation system enzymes, as the activity of Na-ATPase activity decreased, whereas Mg-ATPase activity increased. Moreover, total energy reserves of the mussels significantly decreased at higher cadmium concentrations, suggesting the animals struggled with cadmium toxicity. These results highlight that cadmium levels found in the environment can impact multiple metabolic biomarkers, underscoring their potential use in monitoring metal pollution.
Keywords: Cadmium, Mussel, Toxicity, Biomarker

EFFECTS OF METAL-OXIDE NANOPARTICLES ON THE ANTIOXIDANT AND OSMOREGULATION SYSTEMS OF FRESHWATER FISH (*OREOCHROMIS NILOTICUS*) IN DIFFERING SALINITIES

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ABSTRACT
Salinity is one of the most important factors in freshwater ecosystems, as freshwater fish are extremely sensitive to salinity changes. Metal-oxide nanoparticles (NPs) are emerging pollutants for the environment. In this study, *O. niloticus* were exposed to metal-oxide nanoparticles (Al_2O_3, TiO_2 NPs) and/or different salinities (0 and 10 ppt) to investigate the responses of the antioxidant and osmoregulation systems in acute (10 mg NPs/L for 2 days) and chronic (1 mg NPs/L for 20 days) durations. Then, the responses of biomarkers belonging to the antioxidant and osmoregulation systems were investigated. Data showed that activities of the antioxidant system biomarkers such as catalase and superoxide dismutase did not change significantly ($p>0.05$) in acute exposures, though their activities significantly ($p<0.05$) decreased in chronic exposures at both salinities. Similarly, glutathione peroxidase and glutathione reductase activities did not change significantly in acute exposures, but their activities decreased significantly in chronic exposures. To investigate the response of the osmoregulation system of fish, activities of Na,K-ATPase, Mg-ATPase and Ca-ATPase were measured in the gill. Salinity increase caused significant decreases in ATPase activities of control fish. Likewise, salt+NP exposures generally caused significant decreases in ATPase activities compared to salinity control, especially in chronic exposures. Data revealed that, concerning NP toxicity, salinity increase was not a predominant factor in the antioxidant system of fish, though it did significantly influence on the osmoregulation system.
Keywords: Antioxidant, Osmoregulation, Nanoparticle, Fish, Salinity

ON OPTICAL SOLITON SOLUTIONS OF PERTURBED FOKAS-LENELLS EQUATION HAVING PARABOLIC LAW WITH NONLOCAL NONLINEARITY IN THE PRESENCE OF SPATIO-TEMPORAL DISPERSION

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ABSTRACT

This study investigates the optical soliton solutions of a perturbed Fokas–Lenells equation characterized by a parabolic law with nonlocal nonlinearity. The considered model incorporates higher-order dispersive and nonlinear effects, including spatio-temporal dispersion and self-steepening terms. This equation, which has contributed significantly to the complex optical transmission trend in recent years with the terms it contains, expresses the pulse propagation in optics. In order to explore the exact wave dynamics of the system, a recently developed and contemporary analytical technique, known as the addendum to the Kudryashov method, is

employed. This novel approach enables the construction of a wide class of optical soliton solutions. As a result, bright, dark, and W-shaped like soliton solutions are successfully derived under specific parametric constraints. The influence of various parameters on the soliton structures is examined. The derived findings are further substantiated through a series of illustrative plots, where two-dimensional (2D) and three-dimensional (3D) graphical depictions are presented to visualize the amplitude and spatial-temporal evolution of the obtained solitons. Although no restrictions were encountered during the study, it is also known that the model has not been investigated before with the addendum to the Kudryashov method. The results obtained contain implications that will be taken into consideration not only for the model studied but also for other studies and researchers in the field of nonlinear optics in general.

Keywords: Optical solitons, The perturbed Fokas-Lenells equation, The addendum to the Kudryashov's method, W-shape like soliton

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YAPAY ZEKÂ TEKNOLOJİLERİNDE BÜYÜME DİNAMİKLERİ MODELİNİN YENİDEN TESTİ: PANEL VERİ EKONOMETRİSİ İLE AMPİRİK BULGULAR

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ÖZET
Bu çalışma, yapay zekâ teknolojilerinde öne çıkan ülkelerin büyüme dinamiklerini açıklamak amacıyla politika, yatırım ve beşerî sermaye bileşenlerinin etkisini panel veri analizi yoluyla ekonometrik bir çerçevede analiz etmektedir. Yapay zekâ, son yıllarda sadece teknolojik değil, aynı zamanda ekonomik ve toplumsal dönüşüm aracı olarak da görülmektedir. Bununla birlikte son yıllarda uluslararası örgütler tarafından yayınlanan teknolojiye ilişin raporların çoğunda yapay zekânın geleceği şekillendirmedeki rolüne vurgu yapılmaktadır. Bu araştırmada, yapay zekâ patent üretimi; Ar-Ge harcamaları, araştırmacı yoğunluğu, bilimsel yayın üretkenliği ve devlet teşvikleri gibi göstergelerle ilişkilendirilmiştir. Bu çerçevede, yapay zekâ teknolojilerinde büyüme dinamiklerini belirleyen temel faktörler; makroekonomik, bilimsel ve teknolojik göstergeler arasındaki ilişkiler ışığında ekonometrik bir çerçevede analiz edilmektedir. Analizde, 2005-2020 yılları arasında en fazla yapay zekâ patenti üreten ülkelerin panel verileri kullanılmış olup, dinamik panel veri analizinde Sistem Genelleştirilmiş Momentler (S-GMM) yöntemi kullanılmıştır. Daha önceden aynı yazar tarafından geliştirilen model, devlet teşvikleri değişkeni eklenerek genişletilmiş ve güncel verilerle yeniden test edilmiştir. Elde edilen ön bulgular, yapay zekâ teknolojilerinin gelişimi için sadece finansal yatırımların değil, aynı zamanda nitelikli insan kaynağına ve bilimsel üretkenliğe odaklanan bütüncül politika yaklaşımlarının gerekli olduğunu göstermektedir. Ön bulgular, Ar-Ge harcamalarının ve araştırmacı sayısının yapay zekâ patent üretimi üzerinde güçlü ve pozitif bir etkisi olduğunu göstermektedir. Ayrıca, modele yeni eklenen devlet destek mekanizmalarının uzun vadede inovasyon süreçlerine katkı sağladığı belirlenmiştir. Bununla birlikte, uluslararası iş birlikleri ve büyük ölçekli özel sektör yatırımlarının, yenilikçi yapay zekâ ekosistemlerinin gelişimini hızlandırdığı tespit edilmiştir.Bu çalışma, yapay zekâ politikalarının bilimsel ve ekonomik temellerini değerlendirerek, karar alıcılara ve politika yapıcılara yönelik ampirik bulgular ışığında stratejik öneriler sunmayı hedeflemektedir.
Anahtar Kelimeler: Yapay Zekâ, Ar-Ge Harcamaları, Devlet Teşvikleri, Beşerî Sermaye, Patent Analizi, Panel Veri Ekonometrisi

REVISITING THE GROWTH DYNAMICS MODEL IN ARTIFICIAL INTELLIGENCE TECHNOLOGIES: EMPIRICAL EVIDENCE THROUGH PANEL DATA ECONOMETRICS

ABSTRACT

This study aims to analyze the impact of policy, investment, and human capital components on the growth dynamics of leading countries in artificial intelligence (AI) technologies within an econometric framework using panel data analysis. In recent years, AI has been seen not only as a technological tool but also as a driver of economic and societal transformation. Furthermore, recent reports published by international organizations consistently emphasize AI's critical role in shaping the future.This research associates AI patent production with indicators such as R&D expenditures, researcher intensity, scientific publication productivity, and government incentives. Accordingly, the key factors determining growth in AI technologies are analyzed econometrically considering the interrelations among macroeconomic, scientific, and technological indicators. The analysis is based on panel data from countries with the highest number of AI patents between 2005 and 2020, employing the System Generalized Method of Moments (S-GMM) for dynamic panel data estimation. The model, previously proposed by the same author, has been revised by incorporating the government support variable and retested using updated data.The preliminary findings indicate that the development of AI technologies requires not only financial investments but also integrated policy approaches focusing on qualified human capital and scientific productivity. Results reveal that R&D expenditures and the number of researchers have a strong and positive impact on AI patent production. Moreover, the newly added variable—government support mechanisms—has been found to contribute significantly to innovation processes in the long run. Additionally, international collaborations and large-scale private sector investments are shown to accelerate the development of innovative AI ecosystems.This study aims to provide strategic recommendations to policymakers and decision-makers based on empirical evidence by evaluating the scientific and economic foundations of AI policies.

Keywords: Artificial Intelligence, R&D Expenditures, Government Incentives, Human Capital, Patent Analysis, Panel Data Econometrics

KONYA KARAPINAR ÇÖL EKOSISTEMINDE İKLIM DEĞIŞIKLIĞININ BAZI TÜRLERIN (EPHEDRA MAJÖR SUBS. MAJOR- HUM VEYA DENIZ ÜZÜMÜ, ATRIPLEX CANESCENS (PURSH) NUTT. – UNLUCA) FENOLOJILERI ÜZERINE ETKILERININ ARAŞTIRILMASI VE HABITAT GEREKSINIMLERININ TESPITI - İLK KAYIT

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ÖZET
İklim değişikliği son yıllarda sadece bilim dallarının değil günlük yaşamın bir parçası olacak kadar hissedilir boyutlara ulaşmıştır. Dünyada ve Türkiye'de süregelen iklim kuşaklarının kayması sonucu insanoğlu, iklim senaryolarının en çok uyarı yaptığı kuraklığa sadece su yönetiminde bazı yöntem ve teknolojiler kullanarak çözüm getirilemeyeceği gerçeği ile karşı karşıya kalmıştır. Vejetasyonun varlığı her ne kadar suyun varlığına bağlı görünse de biyoçeşitlilik birçok faktörün etki-tepki döngüsüyle organize olmaktadır. Bu durum iklim değişikliği konusunda fenoloji çalışmalarını zorunlu kılmaktadır. İklim değişikliğinin biyoçeşitlilik üzerine etkilerini azaltmak için çözüm önerisi bulmak amacıyla, bu çalışma çöl ekosisteminin hüküm sürdüğü Konya Karapınar koruma alanında 2018-21 yılları arasında ekonomik değeri yüksek üç tür ile yürütülmüştür. Çalışma materyalini Ephedra majör subs. Major- Hum veya Deniz Üzümü, Atriplex canescens (Pursh) Nutt. – Unluca oluşturmaktadır. Fenolojik evreler; çiçek, meyve ve tohum olarak ele alınmıştır. Fenolojik evrelerin habitat gereksinimleri Meteoroloji Genel Müdürlüğü'nden alınan hava sıcaklığı, toprak kök derinliğinde nem, toprak yüzey ve kök derinliği (5-20 cm) sıcaklığı, havadaki bağıl nem, yağış, rüzgâr, parametrelerinin maksimum, minimum ve ortalama değerlerinin saatlik verileri fenolojik evreler ile ilişkilendirilerek tespit edilmiştir. Çalışmanın sonucunda fenolojik evrelerin başlangıcının sadece hava sıcaklığı ve yağışa bağlı olarak değil, aynı zamanda kök derinliğinin minimum sıcaklık seyrine de bağlı olarak gerçekleştiği tespit edilmiştir. Her iki tür de Çalımsı bitkiler taksonunda yer almaktadır. Ephedra majör için Genel olarak tohum oluşumunu hızlandıran durumun; kök derinliği, hava sıcaklığı ve nem değerlerindeki değişim farkın %10'un üstüne çıkması olduğu düşünülmektedir. Atriplex tohum oluşturmak için çiçek açmak için meydana gelen iklim koşullarını beklediği tespit edilmiştir. Değişik coğrafyalarda hayatta kalmasında bu adaptasyon mekanizmasının etkili olduğu düşünülmektedir.
Ekonomik ve ekolojik değeri yüksek türlerin habitat gereksinimlerinin tespiti kayan iklim kuşaklarında hayat bulma şanslarını arttıracaktır. Bu çalışma biyoçeşitliliğin devamı için temel bir çalışma niteliği taşımaktadır. İklim değişikliğinin biyoçeşitlilik üzerindeki baskısını azaltmak ve türlerin sürdürülebilirliğini sağlamak için bu tür fenoloji çalışmaları çoğaltılmalıdır.
Anahtar Kelimeler: Zygophyllum Fabago, Hordeum Murinum ve Bromus Tectorum, fenoloji, iklim değişikliği, vejetasyon

INVESTIGATION OF THE EFFECTS OF CLIMATE CHANGE ON THE PHENOLOGY OF CERTAIN SPECIES (EPHEDRA MAJOR SUBS. MAJOR – HUM OR SEA GRAPE, ATRIPLEX CANESCENS (PURSH) NUTT. – FOURWING SALTBUSH) AND DETERMINATION OF THEIR HABITAT REQUIREMENTS IN THE KONYA KARAPINAR DESERT ECOSYSTEM – FIRST DETECTION

ABSTRACT

In recent years, climate change has reached such a noticeable level that it has become a part of not only science but also daily life. As a result of the ongoing shift in climate zones in the world and in Turkiye, humanity has been faced with the fact that the drought, for which climate scenarios warn the most, cannot be solved by using only some methods and technologies in water management. Although the existence of vegetation seems to depend on the presence of water, biodiversity is organized by the action-reaction cycle of many factors. This situation necessitates phenology studies on climate change. In order to find a solution to reduce the effects of climate change on biodiversity, this study was carried out with three species of high economic value between 2018-21 in Konya Karapınar conservation area, where the desert ecosystem prevails. The study material consists of Ephedra majör subs. Major- Hum veya Deniz Üzümü, Atriplex canescens (Pursh) Nutt. – Unluca Phenological stages are approached as flower, fruit (maturity) and seed stages. Habitat requirements of phenological stages are air temperature taken from the General Directorate of Meteorology, humidity at soil root depth, soil surface and root depth (5-20 cm) temperature, relative humidity in the air, Hourly data of maximum, minimum and average values of precipitation, wind parameters were determined by associating them with phenological stages. As a result of the study, it was determined that the onset of phenological stages depends not only on air temperature and precipitation, but also on the minimum temperature at the root depth. Both species are classified within the taxon of shrubby plants. For Ephedra major, it is generally believed that the conditions accelerating seed formation are related to root depth, air temperature, and changes in humidity values exceeding 10%. It has been observed that Atriplex waits for climatic conditions that facilitate flowering in order to produce seeds. This adaptive mechanism is thought to play a crucial role in their survival across various geographical regions.Determining the habitat requirements of species with high economic and ecological value will increase their chances of finding life in shifting climate zones. This study is a fundamental study for the continuation of biodiversity. Such phenology studies should be replicated to reduce the pressure of climate change on biodiversity.

Keywords: Zygophyllum Fabago, Hordeum Murinum and Bromus Tectorum, phenology, climate change

IMPACTS OF TROPICAL CYCLONE SITRANG ON THE SHRIMP INDUSTRY: A CASE STUDY FROM THE COASTAL REGION OF BANGLADESH

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ABSTRACT

Shrimp farming regions of Bangladesh are highly vulnerable to natural disasters like cyclones due to their geographical location. This study investigated the impact of cyclone Sitrang on shrimp farming in a sub-district of Satkhira, southwest Bangladesh, the epicenter of Sitrang. The research focused on 58 shrimp farms directly affected by the cyclone Sitrang, with data collected between December 2022 and January 2023. A structured questionnaire was used to assess the demographic, economic, and environmental impacts of cyclone Sitrang on shrimp farming and the local community. Our research findings revealed that cyclone Sitrang notably diminished profitability in both primary species (*Penaeus monodon*) and co-cultured secondary species, primarily due to disruption in local supply chain. Shrimp farms of various sizes surveyed have significantly increased seasonal employment to address infrastructural damage while retaining permanent staffing levels. This has resulted in notable rise in the number of seasonal workers: small farms by 352%, medium farms by 227%, and large farms by 556%, leading to an overall average increase of 396%. Cyclone Sitrang impacted both non-fixed costs (slightly increased) and net income (significantly decreased) for small, medium and large farms in the post-Sitrang period. The benefit-cost ratio declined significantly across all farm sizes, indicating reduced financial viability of shrimp farms during post-Sitrang period. Additionally, farmers reported increased incidences of shrimp diseases including white spots, yellow discoloration, and shell abnormalities, likely exacerbated by the cyclone Sitrang further disrupted farm operations and financial outcomes.

BIO-SEQUENCE ANALYZER: A TOOL FOR CLASSIFICATION OF BIO-MOLECULAR STRUCTURES

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ABSTRACT

DNA structures are crucial in biological processes such as replication, transcription, and translation. Traditional methodologies for predicting these structures primarily utilize energy minimization algorithms and machine learning techniques, which can be computationally expensive and often lack transparency. This paper introduces an innovative rule-based method that leverages a matrix insertion-deletion algorithm grounded in formal language theory to systematically identify and classify DNA structural motifs, including hairpins, stem loops, pseudoknots, and cloverleaf patterns. The approach applies predefined rule matrices to iteratively reduce DNA sequences, effectively capturing structural patterns through explicit insertion and deletion operations. To further enhance interpretability, we integrate 3D visualization techniques that clearly represent the predicted structural motifs. Our computational framework also utilizes formal grammars, rigorously defining each motif, and bridging bioinformatics with automata theory. Experimental evaluations conducted on synthetic and natural DNA sequences demonstrate that the proposed method is highly computationally efficient, accurately detects well-established structural motifs, and provides a transparent, interpretable model suitable for advanced genomic analyses.

MEMORY ENHANCING AND NEUROPROTECTIVE EFFECTS OF APOMORPHINE IN A RAT MODEL OF DEMENTIA

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ABSTRACT
Oxidative stress from generation of increased reactive oxygen species or has been reported to play an important role in dementia. Oxidative stress due to free radicals of oxygen or reactive oxygen species could be precipitating factors in the etiology of dementia. Apomorphine has been reported to have neuroprotective effects. To monitor memory enhancing and neuroprotective effects of apomorphine, we determined the antioxidant enzymes activities, lipid peroxidation, acetylcholine esterase (AChE) activity in brain and plasma, following repetitive administration of apomorphine in rat model of dementia. Biogenic amine levels were also monitored in hippocampus. Repeated administration of scopolamine was taken as an animal model of dementia. Decreased glutathione peroxidase, superoxide dismutase and catalase activities were observed in these animal models of dementia. While increased lipid peroxidation was also observed in the brain and plasma samples. The results showed significant effects of apomorphine. The activities of antioxidant enzymes displayed increased activities in both brain and plasma. Glutathione peroxidase and catalase activities were found to be significantly higher in brain and plasma of apomorphine treated rats. Superoxide dismutase (SOD) was significantly decreased in plasma of scopolamine injected rats; and a decreased tendency (non-significant) of SOD in brain was also observed. AChE activity in brain and plasma was significantly decreased in scopolamine treated rats. Learning and memory of rats in the present study was assessed by Morris Water Maze (MWM). Short-term memory and long-term memory were impaired significantly in scopolamine treated rats, which was prevented by apomorphine. Moreover, a marked decrease in biogenic amines was also found in the brain of scopolamine treated rats and was reverted in apomorphine treated rats. Results showed that scopolamine-treatment induced memory impairment and induced oxidative stress in rats as compared to saline-treated controls. These impairments were significantly restored by the apomorphine administration. In conclusion, our data suggests that an apomorphine at the dose of 1 mg/kg could be a potential therapeutic agent to treat dementia and
related disorders.

Keywords: Morris water maze, Apomorphine, Scopolamine, AChE, Glutathione peroxidise, Catalase, Superoxide, dismutase, Lipid peroxidation, Biogenic amines

AIT RESONANCE AND FLAT BAND IN 1D ACOUSTIC QUASI-PERIODIC STRUCTURE

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ABSTRACT
We study a quasi-periodic system consisting of a periodicity of segments of a length d_1 and N' closed resonators of lengths d_{2j}, in which the resonators lengths depend on each other according to an arithmetic sequence. In the one hand, we take a single resonator and we indicate the existence of the AIT resonance and we show the appearance of new discrete modes located between two transmission zeros. These discrete modes are located around specific frequencies with higher transmission rates and quality factors. If we start increasing the number of resonators, we get more AIT resonances, and their resonance frequencies depend on the interaction between the modes of each resonator. The creation of resonators of different lengths in a perfect comb-like quasi-periodic system gives rise to very thin flat bands located inside the band gaps. If we consider that we have (j) resonators of different lengths, in this case there will be (j-1) flat bands. On the other hand, we study the effect of introducing five defects at the resonators located in the middle of the quasi-periodic structure, these defects have different lengths d_{02j}, the creation of geometrical defects give rise to defect modes inside the band gaps. These results are suitable for the application of multichannel filters.
Keywords: AIT resonance, Geometrical Defect, Quasi-Periodic System, Arithmetic Sequence, Flat Band

ÜNİVERSİTE ÖĞRENCİLERİNİN DİJİTAL BAĞIMLILIĞA İLİŞKİN METAFORİK ALGILARI

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ÖZET
Dijital teknolojilerin hayatın her alanına nüfuz etmesiyle birlikte bireylerin dijital araçlara olan bağımlılığı giderek artmaktadır. Bu durum özellikle genç yetişkinler olan üniversite öğrencileri açısından psikolojik, sosyal ve akademik boyutlarda çeşitli sorunları da beraberinde getirmektedir. Bu çalışmanın amacı, üniversite öğrencilerinin dijital bağımlılığa ilişkin algılarını metaforlar aracılığıyla ortaya koymaktır.Araştırma, nitel araştırma yöntemlerinden olgubilim (phenomenology) deseni ile yürütülmüştür. Çalışma grubu, Türkiye'deki bir devlet üniversitesinde öğrenim gören 100 öğrenciden oluşmaktadır. Veri toplama aracı olarak katılımcılara "Dijital bağımlılık … gibidir çünkü …" şeklindeki açık uçlu cümle verilmiş ve öğrencilerin bu ifadeyi tamamlamaları istenmiştir. Elde edilen veriler içerik analizi yöntemiyle değerlendirilmiş; benzer özellik gösteren metaforlar kategorilere ayrılmış ve tematik bir yapı oluşturulmuştur.Bulgular, öğrencilerin dijital bağımlılığı çoğunlukla olumsuz metaforlarla (örneğin; "kafes", "bataklık", "sanal hapishane", "ayna", "uçurum") tanımladığını ortaya koymuştur. Bu metaforlar dört ana temada toplanmıştır: bağımlılık ve esaret, kaçış ve yalnızlık, kontrol kaybı, zaman ve enerji kaybı. Öğrencilerin dijital bağımlılığı bir tehdit ve kısıtlayıcı unsur olarak algıladığı görülmektedir. Bu durum, dijitalleşmenin bireysel yaşam üzerindeki etkilerinin daha derinlikli bir şekilde anlaşılması açısından önem taşımaktadır.Çalışmanın sonucunda, dijital bağımlılık konusunda üniversite öğrencilerine yönelik farkındalık artırıcı programların geliştirilmesi önerilmiştir. Ayrıca metafor analizi, dijital bağımlılığın birey zihnindeki yerini kavramak açısından etkili bir yöntem olarak değerlendirilmektedir.
Anahtar Kelimeler: Dijital Bağımlılık, Metafor Analizi, Üniversite Öğrencileri.

UNIVERSITY STUDENTS' METAPHORICAL PERCEPTIONS OF DIGITAL ADDICTION

ABSTRACT

With the penetration of digital technologies into every aspect of life, individuals addiction to digital tools is increasing. This situation brings about various psychological, social and academic problems, especially for university students who are young adults. The aim of this study is to reveal university students' perceptions of digital addiction through metaphors.

The research was conducted using the phenomenology design, one of the qualitative research methods. The study group consists of 100 students studying at a state university in Turkey. As a data collection tool, the open-ended sentence "Digital addiction is like ... because ..." was given to the participants and the students were asked to complete this statement. The obtained data were evaluated with the content analysis method; metaphors with similar characteristics were categorized and a thematic structure was created.The findings revealed that students mostly defined digital addiction with negative metaphors (e.g. “cage”, “swamp”, “virtual prison”, “mirror”, “cliff”). These metaphors were grouped under four main themes: addiction and captivity, escape and loneliness, loss of control, loss of time and energy. It is seen that students perceive digital addiction as a threat and a restrictive element. This situation is important for a deeper understanding of the effects of digitalization on individual lives.As a result of the study, it was suggested that awareness-raising programs be developed for university students on digital addiction. In addition, metaphor analysis is considered an effective method in understanding the place of digital addiction in the individual mind.

Keywords: Digital Addiction, Metaphor Analysis, University Students.

THE ROLE OF AI IN PROMOTING EQUITABLE ACCESS TO CLEAN WATER IN RURAL COMMUNITIES

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ABSTRACT
Access to clean water is a significant challenge for rural communities around the globe, worsened by environmental, infrastructural, and socio-economic obstacles. This review examines how Artificial Intelligence (AI) is transforming water management systems to provide fair access to safe drinking water. Innovations driven by AI, such as predictive analytics, smart sensors, and automated water distribution systems, present sustainable solutions for resource allocation, contamination detection, and effective infrastructure maintenance. Rural regions frequently face water scarcity due to climate change, inadequate governance, and inefficient water distribution systems. AI-based forecasting models can predict drought patterns, optimize water usage, and minimize waste by analyzing real-time data. Machine learning algorithms combined with remote sensing technologies improve groundwater monitoring and help identify contamination risks before they develop into public health issues. Furthermore, AI-driven automation in water treatment facilities enhances efficiency, alleviating pressure on underdeveloped infrastructure. However, challenges like the digital divide, high implementation costs, and data privacy concerns impede the adoption of AI in rural areas. Overcoming these obstacles requires collaborative efforts from governments, the private sector, and local communities to promote AI-driven water management policies. This study highlights the importance of inclusive AI frameworks that focus on marginalized populations, ensuring that technological progress contributes to social equity. By harnessing AI's potential, rural communities can secure sustainable and equitable access to clean water, reducing health disparities and fostering economic resilience. Future research should aim at developing scalable AI solutions that are both cost-effective and adaptable to various geographical and socio-economic contexts.

Keywords: Artificial Intelligence (AI), Clean Water Access, Rural Communities, Water Management

APPLICATION OF NEUROCOMPUTING IN ADAPTIVE CONTROL OF LARGE SCALE AEROSPACE SYSTEMS

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ABSTRACT
We are engaged in solving two difficult problems in adaptive control of the large-scale time-variant aerospace system. One is parameter identification of time-variant continuous-time state-space model; the other is how to solve algebraic Riccati equation A R E of large order efficiently. In our approach, two neural networks are employed to independently solve both the system identification problem and the A R E associated with the optimal control problem. Thus the identification and the control computation are combined in closed-loop, adaptive, real-time control system. The advantage of this approach is that the neural networks converge to their solutions very quickly and simultaneously
Keywords: Large-scale system, System identification, Hopfield neural network, Algebraic Riccati equation, Recurrent neural network.

CHEMICAL MORDANTING FOR NATURAL DYEING OF FABRICS

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ABSTRACT
Green products are having positions in all applied fields particularly in textiles. Plant based natural colorants have been remained in past decades in textile, food and other fields. However, their low fastness in the key unlike which has been improving having chemical mordants. Sustainable salts of metals are being used to develop the colorant shades on cotton, wool, silk, nylon, polyester, Lycos, leap etc. Their salt solutions are used before and after dyeing at selected condition. This presentation will give overview of chemical mordants, their type, applications, mode of action and shade development process, in natural dyeing of fabrics using plants and extracts

ZEOLİTLERİN GÜBRE POTANSİYELİ: BİR SERA DENEMESİ

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ÖZET
Dünya nüfusu hızla artmakta ve buna paralel olarak gıda ihtiyacı da aynı hızda artmaktadır. Tarım alanlarının sınırlı olması nedeniyle birim alandan alınan verimin artması için aşırı gübre kullanımı gün geçtikçe artmaktadır. Ancak gübre gibi tarımsal girdilerin aşırı kullanımı ile birlikte tarımsal verim artsa da ilerleyen yıllarda bu durumun sürdürülebilir olmadığı anlaşılmıştır. Özellikle sulama ile birlikte yıkanan gübreler hem yeraltı su kaynaklarını hem de çevreyi kirleterek ekosistemde olumsuzluklar yaratmaktadır. Gübreden kaynaklanan bu olumsuzlukları azaltmak ya da sonlandırmak için yenilikçi ve sürdürülebilir çözüm yollarına ihtiyaç duyulmaktadır. Zeolit, bu bağlamda araştırılan ve gelecekte bu alanda kullanım potansiyeli yüksek bir mineral türüdür. Zeolit, içerisinde farklı boyutlarda gözeneklerin bulunduğu, yüksek su tutma kapasitesi ve yüksek katyon değişim kapasitesine sahip kristalin alüminosilikattır. Zeolitlerin sahip olduğu bu eşsiz özelliklerden dolayı tarımdan sanayiye oldukça geniş bir uygulama ve araştırma alanı bulunmaktadır. Bu çalışmada sürdürülebilir tarım uygulamaları için zeolit bazlı gübre üretimi, karakterizasyonu ve bitkiler üzerindeki etkileri incelenmiştir. İlk olarak temin edilen doğal zeolit minerali mekanik aktivasyon işleminden geçirilerek farklı boyut aralıklarına indirgenmiştir. Ardından katı:katı metod optimize edilerek amonyum nitrat gübresi zeolit mineraline yüklenmiş ve zeolit bazlı bir gübre oluşturulmuştur. Örnekler çeşitli karakterizasyon teknikleri ile karakterize edilmiş ve ardından oluşturulan zeolit bazlı gübrenin bitki biyoması üzerindeki etkilerini ve gübre olarak kullanılma potansiyelini araştırmak için sera denemesi yapılmıştır. Bu çalışmada marul bitkisi kullanılmış olup sera denemesi sırasında ve sonrasında büyüme parametreleri alınmıştır. Bu çalışmanın sonucuna göre, üretilen zeolit bazlı gübrenin verim ve kalite üzerine pozitif anlamda katkı sağladığı ve sürdürülebilir tarım uygulamalarında gübre olarak değerlendirilme potansiyelinin yüksek olduğu sonucuna varılmıştır.

Anahtar Kelimeler: Doğal zeolit, kimyasal gübre, amonyum nitrat.
Teşekkür: Bu çalışma Mehmet Ufuk Aslan'ın doktora tezinin parçasıdır. Bu çalışma Türkiye Bilimsel ve Teknolojik Araştırma Kurumu (TÜBİTAK) 2244 Sanayi Doktora Programı kapsamında hazırlanmıştır (Proje no: 118C156). Bu çalışma Mersin Üniversitesi Bilimsel Araştırma Projeleri Koordinasyon Birimi tarafından desteklenmiştir. Proje numarası: 2022-2-TP3-4728. Bu çalışmayı desteklerinden dolayı Toros Tarım A.Ş.'ye teşekkürlerimizi sunarız.

FERTILIZER POTENTIAL OF ZEOLITES; A GREENHOUSE EXPERIMENT

ABSTRACT

The world population is rapidly increasing and the need for food is increasing at the same rate. Due to the limited agricultural lands, excessive fertilizer use is increasing day by day in order to increase the yield obtained from the unit area. However, although agricultural yield increases with the excessive use of agricultural inputs such as fertilizers, it has been understood in the following years that this situation is not sustainable. Especially fertilizers washed with irrigation pollute both underground water resources and the environment and create negativities in the ecosystem. Innovative and sustainable solutions are needed to reduce or end these negativities caused by fertilizers. Zeolite is a mineral type that is researched in this context and has a high potential for use in this field in the future. Zeolite is a crystalline aluminosilicate with pores of different sizes, high water retention capacity and high cation exchange capacity. Due to these unique properties of zeolites, there is a very wide application and research area from agriculture to industry. In this study, zeolite-based fertilizer production, characterization and effects on plants were examined for sustainable agricultural applications. First, the obtained natural zeolite mineral was reduced to different size ranges by mechanical activation process. Then, by optimizing the solid:solid method, ammonium nitrate fertilizer was loaded onto the zeolite mineral and a zeolite-based fertilizer was formed. The samples were characterized by various characterization techniques and then a greenhouse trial was conducted to investigate the effects of the zeolite-based fertilizer on plant biomass and its potential to be used as a fertilizer. Lettuce plants were used in this study and growth parameters were taken during and after the greenhouse trial. According to the results of this study, it was concluded that the produced zeolite-based fertilizer contributed positively to yield and quality and has a high potential to be used as a fertilizer in sustainable agricultural practices.

Keywords: Natural zeolite, chemical fertilizer, ammonium nitrate.

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APTAMER: A TARGETED CANCER IMMUNOTHERAPY

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ABSTRACT

Aptamers are single-stranded oligonucleotides that specifically bind and interact with their corresponding targets, including proteins and cells, through unique three-dimensional structures. It has been also called "chemical antibody" which displays the specific affinity to target molecules compared to that of antibodies and possesses several therapeutic advantages over antibodies in terms of size, accessibility to synthesis, and modification. In addition they showed considerable bio stability, versatile chemical modification, low immunogenicity and quick tissue penetration. The process of selecting an aptamer is called Systematic Evolution of Ligands by Exponential Enrichment (SELEX). Currently, new types of aptamers have been reported and attracted many scientists' interesting. Due to simplicity of chemical modification and ready-made molecular engineering, scientists have developed newly designed aptamers conjugated with a wide range of therapeutics, aptamer-drug conjugates; ApDCs, from chemotherapy to phototherapy, gene therapy, and vaccines. ApDCs display synergistic therapeutic effects in cancer treatment. In this review, we list the aptamers that target tumor surface biomarkers and summarize the representative applications of aptamers. Conjugation of aptamers with anti-cancer drugs and nano-vehicles will facilitate innovative applications of aptamer-based cancer therapeutics. Thus, aptamer-embedded drug delivery systems offer an unprecedented opportunity in bioanalysis and biomedicine. In this short review, we endeavour to discuss the recent advances in aptamer-based targeted drug delivery platforms for cancer therapy. To date, great achievements regarding the selection, modifications and application of aptamers have been made. However, few aptamer-based products have already successfully entered into clinical and industrial use. Here we also present the limitations and notable advances of aptamer selection.

Keywords: Aptamer, SELEX method, Aptamer-drug conjugates (ApDCs), Targeted drug delivery, Cancer therapy.

INDUSTRIAL HEALTH MONITORING SYSTEM FOR DC MOTORS

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ABSTRACT
Industrial machinery, especially DC motors, are susceptible to faults such as overheating, excessive vibration, and oil leakage, all of which can lead to mechanical failure or hazardous scenarios. This project presents a sensor-based Industrial Health Monitoring System developed using an Arduino Uno for the real-time identification of such faults. The system integrates three sensors—LM35 for temperature monitoring, MPU6050 for detecting vibrations, and an oil leakage sensor for fluid detection—ensuring comprehensive motor health surveillance. When abnormal values are recorded by any sensor, the system takes immediate action: it activates a buzzer, displays the issue on an LCD screen, stops the DC motor automatically, and transmits an alert message to a control room via the SIM800L GSM module. These functions enable real-time alerting and quick response to prevent potential disasters and reduce machine downtime.This intelligent system significantly enhances the reliability and safety of industrial setups by automating the fault detection and response process. It ensures early intervention and provides scope for future upgrades including IoT integration, data logging for diagnostics, and scalability to other industrial equipment.
Keywords: DC Motor Monitoring; Arduino Uno; GSM Alert System; Industrial Safety

FORMULATION AND EVALUATION OF NEEM, TURMERIC, AND TEA TREE OIL-BASED EMULGEL AND ITS EVALUATION FOR ANTIFUNGAL ACTIVITY

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ABSTRACT

The increasing prevalence of superficial fungal infections and the growing resistance to conventional antifungal agents have led to a renewed interest in herbal formulations as effective alternatives. In this study, an herbal emulgel was formulated using Tea Tree oil (Melaleuca alternifolia)**,** Turmeric oil (Curcuma longa)**,** and Neem oil (Azadirachta indica)—each known for their potent antifungal, anti-inflammatory, and wound-healing properties. The aim was to develop a novel, stable, and efficacious topical dosage form for the treatment of dermal fungal infections. Emulgels, which combine the advantages of both emulsions and gels, offer improved drug release, enhanced skin penetration, and better patient compliance due to their non-greasy texture and ease of application. The formulation was prepared using Carbopol 940 as a gelling agent, with Tween 80 and Span 80 serving as emulsifying agents to stabilize the oil phase. The developed emulgels were evaluated for various physicochemical parameters including pH, viscosity, spreadability, extrudability, and homogeneity. Additionally, stability studies were conducted under different storage conditions to assess the formulation's robustness. The antifungal activity of the prepared emulgel was tested in vitro using the agar well diffusion method against fungal strains such as *Candida albicans* and *Aspergillus niger*. The results demonstrated that the optimized formulation exhibited substantial antifungal activity, with clear zones of inhibition indicating strong efficacy. The combination of Tea Tree oil, Turmeric oil, and Neem oil showed a synergistic antifungal effect**,** outperforming individual oil-based preparations. Overall, the study concludes that the formulated herbal emulgel is a promising, natural, and safe alternative to synthetic antifungal treatments, offering a cost-effective solution for managing skin fungal infections with minimal side effects.

Keywords: Emulgel, Tea Tree oil, Turmeric oil, Neem oil, Herbal formulation, Antifungal activity, *Candida albicans*, *Aspergillus niger*, Carbopol 940, Agar well diffusion method

RELATIONSHIP BETWEEN ORGANIC FOOD CONSUMPTION AND ATTENTION PERFORMANCE IN A SAMPLE OF MOROCCAN PRIMARY SCHOOL STUDENTS FROM KHEMISSET

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ABSTRACT
In last decades, as in other countries, Moroccan diet have known great changes involving foods artificial foods and fast food. This study aims to systematically assess associations between organic food consumption and cognition in sample of school children. The study sample included data of 210 school students aging 10–13 years-old, from three elementary school cohorts. We measured all consumed foods including main meals, biscuits, chemicals and life styles. The measured cognitive domains were attention memory (d2R test) and working (N-Back task). We used two statistical approaches to assess associations between organic foods and child cognition: the exposome-wide association study (ExWAS) considering each consumed food independently, and the deletion-substitution-addition algorithm (DSA) considering all exposures simultaneously to build a general model. The results show that child organic food intake was associated with higher fluid intelligence (attention) scores (beta = 1.18; 95% CI = 0.50, 1.87) and higher working memory (N-Back) scores (0.23; 0.05, 0.41), and child fast food intake (−1.25; −2.10, −0.40) was associated with lower attention and memory scores. However, the rural origin that reflect high physical activity. This first comprehensive study of childhood nutrition risk factors suggests that unfavourable child diet, including low organic food consumption adversely and cross-sectionally associate with cognitive function. Unexpected associations were also observed and maybe due to confounding and reverse causality.
Keywords: organic food, cognitive function, d2R test, adolescents, Morocco.

ESTIMATION OF POPULATION PARAMETER FOR TANK GOBY *GLOSSOGOBIUS GIURIS* (HAMILTON, 1822) FROM THE RANI RIVER IN NORTHWESTERN BANGLADESH THROUGHS THE MULTIMODAL APPROACHES

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ABSTRACT

The Tank goby *Glossogobius giuris* (Hamilton 1822) is a nutrient-dense and commercially significant fish species and serves as a bio indicator of water quality.Therefore, the present study was under taken to estimate the population parameters to understand both the current status and yield, and to suggest sustainable management measures for this species, using monthly samples collected from July-November 2023.The study examines various aspects of a small indigenous fish species *G. giurius* (Perciformes: Gobiidae) in the Rani River, Northwestern Bangladesh, including population structure; Length Frequency Distribution (LFD), Length-Length Relationship (LLRs), Length-Weight Relationship (LWRs), Conditions factors (K_A, K_F, K_R), prey-predator status (W_R), Form factor ($a_{3.0}$), Size at sexual maturity (L_m), Natural mortality (M_w). It aims to provide insights into the species ecology and dynamics within its habitat. A diverse range of small species were caught by using traditional fishing gear. The total count was 100 individuals measuring total length and body weight by measuring board and electronic digital balance respectively.In our study LFD showed that the largest 10 cm and smallest 5.40 cm TL.Growth pattern was indicated negative allometric growth based on *b* in LWRs, Allometric condition factor is best suited among other condition for this study.The form factor($a_{.30}$) 0.0106 indicates the elongated body shape.The estimated L_m has been found 6.26 cm, which represents the earlier maturity than Gajner *beel* and Radbanad channel in Bangladesh. The estimated natural mortality (M_w) was 1.17 year^{-1}.This findings would be very effective for further stock assessment (*MSY*, *MEY*,) Exploitation Rate (*E*), Biodiversity Conservation, Government Policy making by establishing suitable mesh size and sustainable management of this tank goby fish not only in our country but also in neighbouring countrie

Keywords:, *Glossogobius giuris*, Conditions Factors, Size at sexual maturity,Natural mortality, Rani River, Bangladesh

ZEOLİT BAZLI YAVAŞ SALINIMLI GÜBRELERDE AKTİVASYON VE MODİFİKASYONUN ETKİLERİ

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ÖZET
Günümüzde artan gıda ihtiyacı, tarım sektöründe daha verimli üretim tekniklerinin geliştirilmesini zorunlu kılmaktadır. Tarımsal verimliliği artırmak amacıyla kullanılan kimyasal gübreler, zamanla çevresel kirliliğe ve ekonomik kayıplara yol açmaktadır. Aşırı gübreleme, bitkilerin ihtiyacından fazla besin elementi sağlanmasına sebep olurken, gübrelerin yağmur ve sulama ile yıkanarak topraktan uzaklaşması, yeraltı sularının kirlenmesine neden olmaktadır. Bu bağlamda, yavaş salınımlı gübreler, bitki besin maddelerinin kontrollü bir şekilde toprağa salınımını sağlayarak hem tarımsal verimi artırmayı hem de çevresel kirliliği önlemeyi hedeflemektedir. Zeolit minerali, yüksek iyon değişim kapasitesi ve gözenekli yapısıyla yavaş salınımlı gübrelerin geliştirilmesi için önemli bir potansiyel taşımaktadır. Bu çalışmada, doğal zeolit mineralinin aktivasyon ve modifikasyon süreçleri ile bitki besin maddesi tutma kapasitesinin artırılması ve yavaş salınımlı gübre formülasyonlarının geliştirilmesi amaçlanmıştır. Klinoptilolit ağırlıklı doğal zeolit, mekanik, termal ve asidik aktivasyon süreçlerinden geçirilerek farklı yüzey özelliklerine sahip hale getirilmiştir. Ardından, sodyum nitrat ile modifikasyon yapılarak iyon değişim kapasitesinin artırılması hedeflenmiştir. Modifiye edilen zeolit, amonyum nitrat içeren bitki besin maddesi ile yüklenmiş ve elde edilen gübre formülasyonlarının karakterizasyonu çeşitli analitik tekniklerle gerçekleştirilmiştir. Yüzey alanı ve gözenek dağılımı analiz edilerek aktivasyon ve modifikasyon süreçlerinin zeolitin besin maddesi tutma kapasitesine etkisi belirlenmiştir. Elde edilen bulgular, aktivasyon ve modifikasyon süreçlerinin zeolitin yüzey alanının önemli ölçüde artırdığını, böylece besin maddelerinin daha uzun süre boyunca kontrollü bir şekilde salındığını göstermektedir. Sonuç olarak, bu çalışma, tarımsal üretimde sürdürülebilirliği destekleyen, çevresel etkileri azaltan ve ekonomik kayıpları minimize eden yeni nesil gübre teknolojilerinin geliştirilmesine katkı sunmaktadır.

Anahtar Kelimeler: Zeolit, yavaş salınımlı gübre, aktivasyon, modifikasyon.
Teşekkür: Bu çalışma Ali Baran Narin'in doktora tezinin parçasıdır. Bu çalışma Türkiye Bilimsel ve Teknolojik Araştırma Kurumu (TÜBİTAK) 2244 Sanayi Doktora Programı kapsamında hazırlanmıştır (Proje no: 118C156). Bu çalışma Mersin Üniversitesi Bilimsel Araştırma Projeleri Koordinasyon Birimi tarafından desteklenmiştir. Proje numarası: 2022-2-TP3-4725. Bu çalışmayı desteklerinden dolayı Toros Tarım A.Ş.'ye teşekkürlerimizi sunarız.

EFFECTS OF ACTIVATION AND MODIFICATION ON ZEOLITE-BASED SLOW-RELEASE FERTILIZERS

ABSTRACT

Today, the increasing demand for food necessitates the development of more efficient production techniques in the agricultural sector. Chemical fertilizers used to enhance agricultural productivity can lead to environmental pollution and economic losses over time. Excessive fertilization provides plants with more nutrients than they need, while the leaching of fertilizers due to rainfall and irrigation causes groundwater contamination. In this context, slow-release fertilizers aim to improve agricultural yield while preventing environmental pollution by ensuring the controlled release of plant nutrients into the soil. Zeolite minerals, with their high ion-exchange capacity and porous structure, hold significant potential for the development of slow-release fertilizers. This study aims to enhance the nutrient retention capacity of natural zeolite minerals through activation and modification processes and to develop slow-release fertilizer formulations. Clinoptilolite-rich natural zeolite was subjected to mechanical, thermal, and acidic activation processes to obtain different surface properties. Subsequently, modification with sodium nitrate was carried out to increase its ion-exchange capacity. The modified zeolite was loaded with ammonium nitrate-containing plant nutrients, and the characterization of the resulting fertilizer formulations was performed using various analytical techniques. Surface area and pore distribution were analyzed to determine the effects of activation and modification processes on the nutrient retention capacity of zeolite. The findings indicate that activation and modification processes significantly increase the surface area of zeolite, enabling the controlled release of nutrients over an extended period. In conclusion, this study contributes to the development of next-generation fertilizer technologies that support sustainable agricultural production, reduce environmental impact, and minimize economic losses.

Keywords: Zeolite, slow-release fertilizer, activation, modification.

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DEVELOPMENT OF TECHNOLOGY FOR IN VITRO PROPAGATION AND STORAGE OF ATROPA BELLADONNA L.

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ABSTRACT
Bulgaria is relatively small in area, it has a rich biological diversity due to the highly varied climatic, geological, topographical and hydrological conditions. The Bulgarian flora is a source of plant species rich in a large set of chemical components – specific substances or groups of compounds that are in limited populations. The species Atropa belladonna L. is distributed in forested areas throughout the country. Due to the presence of atropine and scopolamine, the herb is highly poisonous. The application of modern reproductive technologies provides a chance to evaluate, characterize and preserve the species Atropa belladonna, study them under controlled conditions and return them to their natural habitats for the purpose of their preservation. The effect of BAP on the regeneration response of explants was studied using concentrations of 0.5; 0.7; and 1.0 mg/l. Murashige and Skoog (1969) medium. The best development of the species is reported on the 20th and 30th day on Murashige and Skoog (1962) medium containing 0.5 mg/l BAP. The multiplication factor for this variant is 1:5, and for the control variant 1:4. With increasing observation period, the leaf number indicators change significantly. The low concentration of the studied cytokinin does not allow A. belladonna to realize the maximum of its development potential in controlled conditions.
Keyword: plant genetic resources, in vitro, Atropa belladonna L., BAP, micropropagation

THE IMPACT OF ADDING WALNUT SHELL POWDERS ON THE MORPHOLOGY, THERMAL PROPERTIES, AND MECHANICAL PERFORMANCE OF POLY(LACTIC ACID) (PLA).

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ABSTRACT
Poly(lactic acid) (PLA) is an environmentally friendly material; however, its widespread application is limited by its brittleness, slow crystallization rate, and low heat distortion temperature. To address these shortcomings, this study incorporated walnut shell (WS) powders into PLA. The influence of WS powders on the morphology, as well as the thermal and mechanical properties of PLA, was thoroughly examined. Characterization techniques such as differential scanning calorimetry (DSC), infrared (IR) spectroscopy, polarizing optical microscopy (POM), and various mechanical property tests were employed. The findings revealed that WS powders significantly affected the morphology and improved the thermal and mechanical behavior of PLA. The tensile strength, impact strength, and elongation at break of the PLA/WS composites initially increased with rising WS powder content, peaking at 0.5 wt%, where maximum values of 51.2 MPa, 23.3 MPa, and 19.0% were observed, respectively. Beyond this concentration, these properties declined. Compared to pure PLA, the composites exhibited reduced spherulite grain sizes and the formation of irregular polygonal structures during crystallization. Additionally, the melting, cold crystallization, and glass-transition temperatures of the PLA/WS composites were lower than those of unmodified PLA.
Keywords: Poly(lactic acid), walnut shells, mechanical properties, composites, thermal properties.

SCIENTIFIC ANALYSIS OF THE VULNERABILITY OF *CHAMELEA GALLINA* TO EXPLOITATION AND ENVIRONMENTAL CHANGES

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ABSTRACT
This study analyzes the vulnerability of Chamelea gallina to exploitation and environmental changes in the eastern region of the Moroccan Mediterranean. The objective is to estimate the age of individuals, study biometric relationships, assess the condition index, and evaluate the exploitation level of the species. To this end, growth parameters were measured and correlated

with environmental data collected simultaneously.The results reveal a significant influence of abiotic factors, such as water temperature and oxygenation, on the growth and physiological condition of individuals. This species, exploited for its economic value, is under increasing anthropogenic pressure, which adds to the effects of climate change. These disturbances compromise the sustainability of natural populations and directly affect coastal communities that rely on them for their livelihood. The decline in stocks could lead to notable economic losses and increase vulnerability in already precarious areas. Environmental changes induced by global warming may also alter ecosystem balances. In light of this situation, it is essential to develop sustainable management strategies and resilience policies to preserve *Chamelea gallina* and support local economies that heavily depend on marine resources.

Keywords: *Chamelea gallina*, growth, exploitation, environmental factors, Moroccan Mediterranean.

THE EFFECTS OF NAOH PRETREATMENT, THERMAL PRETREATMENT, AND THEIR COMBINED NAOH-THERMAL METHOD ON BIOMETHANE PRODUCTION DURING THE ANAEROBIC DIGESTION OF WALNUT SHELLS

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ABSTRACT
Anaerobic digestion (AD) of walnut shells (WS) produces limited biomethane yields due to their high fiber content, classifying them as a largely non-biodegradable lignocellulosic biomass. In this study, thermal pretreatment (50–250 °C), alkaline pretreatment (1–5% w/w NaOH), and a combined alkaline-thermal approach (4% w/w NaOH + 150 °C) were evaluated to enhance the anaerobic biodegradability of WS. The highest biomethane yields, 159.9 ± 6.8 mL CH_4.g VS^{-1} and 169.8 ± 6.8 mL CH_4.g VS^{-1}, were obtained following thermal pretreatment at 250 °C and NaOH pretreatment at 4%, respectively. The combined NaOH-thermal pretreatment resulted in the highest biomethane yield of 192.4 ± 8.2 mL CH_4.g VS^{-1} at the end of the AD process, although it exhibited the longest lag phase (3.90 days) and the highest total VFA concentration (1280.1 mg HAc L^{-1}). This superior yield was supported by the highest SCOD/TCOD ratio (0.37 ± 0.02) and the most effective removal of lignocellulosic fibers, with reductions of 41.1 ± 2.7% in cellulose, 35.6 ± 1.8% in hemicellulose, and 58.7 ± 3.2% in lignin. Cumulative biomethane production was successfully modeled using a modified Gompertz equation. This study highlights that thermal, NaOH, and combined NaOH-thermal pretreatments are effective strategies for significantly improving the biomethane yield of WS, even with their high lignin content.
Keywords: Alkaline pretreatment .Biomethane production . Thermal pretreatment . Lignocellulosic removal . Lignocellulosic biomass . Biogas . Alkaline-thermal pretreatment.

NEUROPROTECTIVE EFFECTS OF *ROSMARINUS OFFICINALIS* ETHANOLIC EXTRACT ON COGNITIVE-AFFECTIVE FUNCTIONS AND HIPPOCAMPUS OXIDATIVE STRESS IN WISTAR RATS EXPOSED TO CADMIUM

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ABSTRACT
Rosmarinus officinalis is a plant used in the Mediterranean diet and traditional medicine with various antioxidant and cytoprotective bioactivities. The study aims to investigate the neuroprotective effect of the ethanolic extract of Rosmarinus officinalis against cognitive-affective functions and oxidative stress in Wistar rats exposed to Cadmium (Cd).18 rats of each sex were distributed into three groups: group 1: control): NaCl saline solution (0.9%); group 2: Cd-1 mg/kg + ED; group 3: Cd-1 mg/kg + 200 mg/kg of the ethanolic extract of Rosmarinus officinalis were administered daily for 8 weeks. After the treatment period, the animals were tested in the Y-maze to assess working memory and the Morris water maze to assess learning and spatial memory. The 1 mg/kg dose of Cd+ ED causes impairments in spatial learning and memory in both sexes. In the Y-maze and Morris water maze tests, both males and females expressed a low percentage of alternations, and spatial learning and spatial memory were significantly impaired, suggesting that working memory, learning and spatial memory were affected by Cd at the 1 mg/kg dose + ED. Cd decreased the level of catalase and increased the level of NO in the hippocampus significantly in both sexes ($p < 0.01$). In rats treated with 1 mg/kg of Cd+ or 200 mg/kg of EERO, males and females had high levels of alternation percentages, and spatial learning and memory were improved, with elevated catalase levels and low NO concentrations in the hippocampus in both sexes.Rosmarinus officinalis exerted a powerful positive effect against Cd-induced cognitive impairment through its antioxidant activity, improving spatial learning and memory.
Keywords : Rosarinus officinalis, cadmium, cognitive affective function, oxidative stress, rats.

DOSE-DEPENDENT EFFECTS OF CADMIUM ON ANXIETY-LIKE AND DEPRESSIVE-LIKE BEHAVIORS AND OXIDATIVE STRESS IN THE PREFRONTAL CORTEX OF FEMALE RATS

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ABSTRACT
Cadmium is a heavy metal that represents a human health problem since daily intake through food, water, and simple inhalation (smoking and occupational exposure) exposes humans to this metal. Several studies have shown a direct effect between cadmium exposure and the development of neurodegenerative disorders. The objective of this study was to assess the dose-dependent effect of this metal on anxiety-like and depressive-like behaviors and oxidative stress in the prefrontal cortex of female rats.administering daily subcutaneous injections of four different doses of 25, 50, 75 and 100 mg/kg CD while a control group received 0.9% NaCl. Based on behavioral tests (open field, elevated plus maze and forced swimming), behavioral alterations were detected, particularly anxiety levels and depressive-like behavior. Simultaneously, hippocampal oxidative stress markers (catalase, nitric oxide and lipid peroxidation) were assessed to elucidate the involvement of oxidative stress (OS) in the observed effects. The results show a clear dose-dependent effect of Cd, revealing increased anxiety and depressive-like behaviors at doses of 75 and 100 mg/kg after subchronic Cd exposure. Notably, OS markers showed discernible alterations only at 75 and 100 mg/kg, with no significant variation observed at lower doses (25 and 50 mg/kg).
Our study confirms the dose-dependent effect of Cd exposure, implicating prefrontal cortex OS markers as potential contributors to the observed neurobehavioral changes. Thus, our results highlight OS as a plausible mechanism explaining the underpinnings of the neurotoxic effects observed after cd exposure.
Keywords : Cadmium, dose-dependant, oxidative stress, prefrontal cortex, rats.

ASSESSMENT OF METAL POLLUTION AND PHYSICAL CONDITION USING A BIOLOGICAL BIOINDICATOR: THE ATLANTIC HORSE MACKEREL TRACHURUS *TRACHURUS* CAUGHT ALONG THE ORAN COASTLINE

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ABSTRACT
Marine pollution along the Oran coastline due to heavy metals is a major issue that poses a long-term threat to both the environment and human health. This study aims to assess the environmental quality of the Oran coastal zone using a biological approach based on estimating the levels and bioavailability of two trace elements (copper and lead), along with evaluating the physical condition of *Trachurus trachurus* caught in Oran Bay. Sampling was conducted during the spring season, from March to May 2023, using 45 individual fish.
Metal analysis was performed on both sexes (males and females) by collecting three organs: muscle, liver, and gills. The average concentrations of heavy metals were determined using flame atomic absorption spectrophotometry, taking into account variables such as sex and sampling month.Using *Trachurus trachurus* as a biological indicator for contamination by these micropollutants revealed their presence in all three target organs. The results show that copper accumulation in *Trachurus trachurus* is higher than that of lead. The high condition factor observed in this population (k = 0.9) suggests no signs of overweight, indicating a successful adaptation to local ecological conditions. This reflects favorable conditions for balanced growth, despite environmental and pollution-related challenges.Although the species shows signs of adaptation, the persistence of these contaminants in vital fish organs highlights the urgent need for sustainable management measures and regular monitoring to preserve the marine ecosystem and protect public health.
Keywords: *Trachurus trachurus*, condition factor, marine pollution, lead, copper, Oran Bay.

HORMONLARIN ENDOMETRİYOZİS ÜZERİNDEKİ ETKİSİ

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ÖZET
Endometriyozis, endometriyum dokusunun uterus dışında farklı organlara yerleşmesi ile ortaya çıkan jinekolojik bir hastalıktır. Endometriyozisli hastalarda sıklıkla dismenore (ağrılı menstürasyon), disparoni (ağrılı cinsel ilişki), pelvik ağrı gibi semptomlar yaygın olarak görülmektedir. Östrojen ve progesteron overlerde sentezlenerek hücre proliferasyonunu ve diferansyonunu indükleyerek endometriyal dokunun maturasyonuna katkıda bulunurlar. Endometriyal doku, menstrüal siklus süresince östrojen ve progesteron hormonları etkisi ile düzenli değişim göstermektedir. Östrojen, endometrial doku için güçlü bir mitojen olarak bilinmektedir. Progesteron, östrojenin endometriyum dokusu üzerindeki mitojenik etkisini inhibe ederek diferansyonunu artırır. Progesteronun farklılaştırıcı ve antiproliferatif özelliği endometriyum dokusundaki etkisi az belirgindir. Bundan dolayı endometriyozis nadiren progesteronun etkisine direnç göstermektedir. Östrojen bağımlılığı ve progesteron direnci, endometriyal dokuların apoptoz ve ektopik implantasyonunu azaltmaya, nöroanjiyogenez ve oksidatif stresin artmasına neden olmaktadır. Endometriyozis semptomları olan kadınlarda ağrıyı azaltmada hormonal tedavi cerrahi tedaviye alternatif bir yöntem olabilir. Endometriyozisli hastalarda ağrı birkaç farklı şekilde giderilmeye çalışılır. Over kistleri, retroperitoneal implantlar ve derin nodüllerin çıkarılması gibi cerrahi işlemler ya da farmakolojik olarak gonodotropin salgılatıcı hormon agonistleri, progestinler ve oral kontraseptif ilaçlar aracılığı ile hormonal baskılanma ile tedavi edilebilir. Hastalığın tedavisinde östrojen, progesteron veya kombine oral kontraseptif ilaçlar (OKS) kullanılmaktadır. Hormonal ilaçlar, endometriyozisin oluşturduğu semptomları azaltmak, cerrahi operasyonu ertelemek veya cerrahi işlem sonrasında hastalığın tekrarlanmasını önlemek amacı ile birinci basamak tedavi olarak kullanılmaktadır. Endometriyozisin fizyopatolojosinde reseptör seviyesinde hormonal etkilerin ortaya konulması, hastalığın tedavisinde etkili olacaktır. Bu derlemenin amacı, östrojen ve progesteron hormonlarının endometriyozis tedavisindeki mevcut ve gelecekteki yöntemleri ile ilgili bilgi sunmaktır.
Anahtar Kelimeler: Endometriyozis, östrojen, progesteron

EFFECT OF HORMONES ON ENDOMETRIOSIS

ABSTRACT

Endometriosis is a gynecological disease that occurs when endometrial tissue settles in different organs outside the uterus. Symptoms such as dysmenorrhea (painful menstruation), dyspareunia (painful sexual intercourse), and pelvic pain are commonly observed in patients with endometriosis. Estrogen and progesterone are synthesized in the ovaries and contribute to the maturation of endometrial tissue by inducing cell proliferation and differentiation. Endometrial tissue undergoes regular changes during the menstrual cycle under the influence of estrogen and progesterone hormones. Estrogen is known to be a potent mitogen for endometrial tissue. Progesterone inhibits the mitogenic effect of estrogen on endometrial tissue, increasing its differentiation. The differentiating and antiproliferative properties of progesterone in the endometrial tissue are less clear. Therefore, endometriosis rarely resists the effects of progesterone. Estrogen dependence and progesterone resistance cause a decrease in apoptosis and ectopic implantation of endometrial tissues and increase in neuroangiogenesis and oxidative stress. Hormonal therapy may be an alternative to surgical treatment to reduce pain in women with endometriosis symptoms. In patients with endometriosis, pain is tried to be relieved in several different ways. Ovarian cysts can be treated by surgical procedures such as removal of retroperitoneal implants and deep nodules, or pharmacologically by hormonal suppression with gonadotropin-releasing hormone agonists, progestins, and oral contraceptive drugs. Estrogen, progesterone or combined oral contraceptive drugs (OCS) are used in the treatment of the disease. Hormonal drugs are used as first-line treatment to reduce the symptoms of endometriosis, to postpone surgery, or to prevent recurrence of the disease after surgery. Revealing hormonal effects at the receptor level in the pathophysiology of endometriosis will be effective in the treatment of the disease. The purpose of this review is to provide information on current and future methods of using estrogen and progesterone hormones in the treatment of endometriosis.

Keywords: Endometriosis, estrogen, progesterone

MEDICAL RESPONSIBILITY IN THE DIGITAL AGE

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ABSTRACT
The emergence of innovative health technologies, such as telemedicine, connected devices, and artificial intelligence, presents several promising prospects for the healthcare system, by facilitating access to care and supporting healthcare professionals. However, the expansion of digital technology usage raises numerous questions as well as significant ethical and legal challenges, particularly regarding medical liability. It is primarily about identifying the risks, leading to the application of legal standards governing various activities, such as those regulating the current liability regimes. When a medical error occurs during the use of these new technologies, the essential question focuses on identifying the responsible party. Particularly due to the existence of harm resulting from the use of these new health technologies, attributable to the user physician, the software manufacturer, or the healthcare institution. The relevance of legal and ethical questions related to the evolution of digital medical practice, as well as the new significant risks generated by digital health tools, has led us to examine medical responsibility in the use of these digital tools and artificial intelligence.
Keywords: Innovative medical technology, telemedicine, artificial intelligence, medical liability.

THE IMPACT OF INCORPORATING EUCALYPTUS OIL INTO THE DIET OF BROILER CHICKENS

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ABSTRACT

An experimental study was conducted between April and October in Mostaganem to evaluate the impact of incorporating eucalyptus essential oil into the diet of broiler chickens on meat quality. For this purpose, 1 ml of eucalyptus essential oil was added per liter of drinking water, with the incorporation of Tween 80 to facilitate the dispersion of essential oils.The analysis of the physicochemical characteristics of the meat revealed several significant effects of the treatment. The results showed an increase in dry matter content in the thigh (1.23% vs. 0.681% in the control group) and in the fillet (2.253% vs. 1.908%), indicating a higher nutrient concentration. Additionally, the crude protein content was significantly higher in birds treated with eucalyptus oil, reaching 21.79% in the thigh and 23.283% in the fillet, compared to 19.1% and 19.667%, respectively, in the control group. A slight increase in total lipids was also observed, with 5.12% in the fillet of treated birds compared to 4.533% in the control group.These findings suggest that the use of eucalyptus essential oil could enhance the nutritional and technological quality of broiler chicken meat, particularly by increasing its protein and dry matter content. However, further studies are needed to better understand its effects on other quality parameters and the zootechnical performance of poultry.

Keywords: broiler chicken, eucalyptus essential oil, meat quality, crude protein, dry matter.

MEDICINAL APPLICATIONS OF ALKALOIDS COMPOUNDS

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ABSTRACT
Alkaloids are nitrogen-containing organic compounds found in plants and animals and have a wide range of medicinal applications, including pain relief, anti-malarial treatment, and as anti-cancer agents. They are known for their diverse pharmacological activities, including analgesic, antipyretic, anti-inflammatory, and antibacterial effects. The aim of this study was to discuss on the medicinal applications of alkaloids compounds. the specific medicinal applications of alkaloids include Pain Relief: Alkaloids like morphine, codeine, and oxycodone are potent analgesics used to relieve severe pain. Anti-Malaria: Quinine, derived from cinchona bark, was the first antimalarial drug and remains effective against multidrug-resistant malaria strains. Anti-Cancer: Some alkaloids, like vincristine and vinblastine, are used in chemotherapy for treating various types of cancer. Anticholinergic: Atropine, an anticholinergic agent, can be used to treat certain types of mushroom poisoning by counteracting the effects of muscarinic toxins. Anti-Asthma: Ephedrine, a stimulant alkaloid, has been used in the treatment of asthma. Anti-Inflammatory: Some alkaloids, like berberine, show anti-inflammatory properties by inhibiting inflammatory pathways. Antibacterials: Alkaloids like berberine and voacafricine A and B exhibit potent antibacterial activity. Examples of alkaloids and their applications are Morphine: A potent opioid analgesic used for pain relief. Codeine: A less potent analgesic and cough suppressant. Quinine: An antimalarial drug derived from cinchona bark. Atropine: An anticholinergic agent used to treat muscarinic poisoning and dilate pupils. Ephedrine: A stimulant used in the treatment of asthma and nasal congestion. Vincristine and Vinblastine: Antitumor alkaloids used in cancer chemotherapy. Berberine: An alkaloid with antibacterial and anti-inflammatory properties. With the availability of different plant species and more are yet do discover their medicinal applications, further researches are highly recommended for the isolations of alkaloids compounds with different medicinal applications.
Keywords: Alkaloids, Medicinal Applications, Plants, Nitrogen.

TRIBOLOGICAL ASSESSMENT OF GRAPHENE AT MACRO, MICRO, AND NANOSCALE

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ABSTRACT
Tribology is the study of friction, wear, and lubrication, focusing on how the interactions between moving surfaces, and very often the lubricant, influence these processes. This is crucial for saving energy, enhancing performance, reducing vibration in the machines, and creating eco-friendly lubricants, and improving the surface properties. In addition, lubrication is universally recognized as the most effective strategy for controlling friction and wear, driving extensive research into the development of high-performance lubricants. Over the past decade, there has been a surge of interest in 2D materials like graphene. Graphene, a single layer of carbon atoms arranged in a two-dimensional honeycomb lattice, has garnered significant attention among scientists due to its outstanding properties, such as a low coefficient of friction, mechanical strength, high thermal and electrical conductivity, and resistance to abrasion and corrosion. Furthermore, graphene is at the center of ongoing research across macro, micro, and nanoscale levels, driven by its remarkable properties and immense potential for future technological advancements. This exceptional material requires further in-depth study, spanning a wide range of applications-from nanoelectronics, and sensors at the nanoscale to composite materials at the macroscale-while also aiming to unravel its behavior under varying conditions to better understand how it influences processes across diverse environments. This study aims to provide a comprehensive review of tribology at the macro, micro, and nanoscale levels of graphene.
Keywords: Graphene, Macrotribology, Microtribology, Nanotribology.

EVOLUTIONARY HISTORY OF VERTEBRATES

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ABSTRACT
After the Cambrian explosion first vertebrates evolved at the start of the Paleozoic era. The earliest fossils of vertebrates belong to Chengjiang biota and lived about 518 million years ago. These include *Haikouichthys*, *Myllokunmingia*, *Zhongjianichthys*, and probably *Yunnanozoon*. The first jawed vertebrates may have appeared in the Ordovician (~445 million years ago) and became common in Devonian period, often known as the "Age of fishes". The two groups of bony fishes, Actinopterygii and Sarcopterygii evolved and became common. By the middle of the Devonian, a lineage of sarcopterygii with both gills and air breathing lungs adapted to life in swampy pool. In the next geological period (carboniferous) amphibians, terrestrial tetrapods evolved. A group of vertebrates the amniotes, with membrane around the embryo allowing it to survive on dry land branched from amphibians tetrapods in the carboniferous period. At the onset of the Mesozoic era, all larger vertebrates groups extinct, this is the largest mass extinction in the earth history. After that many new vertebrates groups emerge to recover this mass extinction that are still around today. This era gave rise to modern ecosystem. On this continent modern amphibians, turtle, crocodilians, lizards and mammal appeared. Dinosaurs, gave rise to birds later in the Mesozoic. In the seas, various groups of marine reptiles and group of fish evolved. At the end of the Mesozoic another extinction event occur those extinct dinosaurs and many other vertebrates groups. The Cenozoic, the current era is sometime called the "age of mammals", because of the dominance of terrestrial environment by that group. Placental mammals have occupied the northern hemisphere while marsupial mammals cover the southern hemisphere.
Keywords: Evolution, Vertebrates, Paleozoic era, Mesozoic era, Cenozoic era.

FORMULATION AND EVALUATION OF OTF OF CETIRIZINE FOR RAPID SYSTEMIC ACTION

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ABSTRACT

Allergy has become one of the most common chronic disorder worldwide, affecting nearly 40% of the global population Hypersensitivity reactions are the root cause of allergies, autoimmune diseases, and transplant rejections. Cetirizine, a second-generation H1 histamine blocker, is widely used to manage allergy-related conditions, particularly hay fever and skin welts in patients. Oral thin films (OTFs) are a pharmaceutical dosage form designed to rapidly dissolve within seconds when placed in the oral cavity. One of the main advantages of oral films is that they may be provided without the need for distilled water, preparing oral thin films convenient to use anywhere and whenever. Oral thin films have low disintegration duration and a high dissolution period, which results in a quick onset of action. The solvent casting method is used to prepared films by initially dissolving the excipients; the mixture was stirred for 15 minutes to achieve a clear solution. The films were dried in a hot air oven at a temperature not exceeding 50°C. Once dried, they were gently peeled from the glass plates. The pre-formulation and post-formulation studies, including Organoleptic analysis, solubility testing, stability assessment, drug content analysis, and microscopic examination were conducted. Each OTF was packaged in silver-coloured aluminium foil to protect it from moisture, heat, and light, with twenty films placed in a box, meeting all necessary packaging requirements. Oral thin films are better than conventional dosage forms because of flexibility, rapid onset of action, improved bioavailability, and increased patient compliance. Oral thin films are customizable, according to specific patient need.

Keywords: Autoimmune disease, rapid systemic action, Solvent Casting method, bioavailability, H1 blocker, patient compliance

CORRELATION STUDY ON ETIOLOGICAL FACTORS OF HEART DISEASE IN DIABETIC PATIENTS IN LAHORE, PAKISTAN

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ABSTRACT

Diabetes is a chronic disorder and inability to process and regulate blood glucose levels. This disorder may arise from excessive secretion of insulin by pancreas in our body. Type I diabetes is a chronic autoimmune disease characterized by deficiency of insulin, resulting in an increase in blood glucose level in body. This dysfunction includes autoimmune destruction of beta cells in pancreas leads to complete lack of insulin production. Type 2 diabetes is most prevalent metabolic disorder characterized by inadequate insulin production and impaired response of tissues to insulin. Global burden of diabetes mellitus represents a significant public health challenge. Heart disease is a serious health condition that affects millions of people. Heart diseases includes coronary artery disease (CAD), myocardial infarction, angina, heart failure, congenital heart disease, atrial fibrillation and heart valve disorder. Etiological factors of heart disease are modifiable factors, conventional factors, environmental factors, non- traditional factors and psychological factors that collectively contribute to diabetes prevalence. Modifiable factors include high blood pressure, obesity and metabolic syndrome while conventional factors include age, gender and family history. Complications related to diabetes like liver cirrhosis, alcohol related liver disease and renal disease also promote cardiovascular disorders. Different risk factors show different level of correlation with each other. Age limit, duration of diabetes and high level of cholesterol has significant level of positive correlation. Moreover, high level of cholesterol in diabetic patients correlate with normal systolic blood pressure which is also an indication of prevalence of heart disease in diabetic patients. Treatment and preventions focus on stress management, lifestyle interventions and balanced diet.

Keywords: Diabetic Heart Disease, cardiovascular complications, Etiological Factors , Correlation Study

ASSESSMENT OF MUNICIPAL SOLID WASTE GENERATION AND MANAGEMENT STRATEGIES IN GOMBE METROPOLIS, GOMBE STATE, NORTHEASTERN NIGERIA

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ABSTRACT

This research was carried out in Gombe Metropolis on solid waste generation and management strategies, with the aim of identifying the various types and sources of solid waste generated, as well as the methods of waste collection and disposal in the study area. A simple random sampling technique was used, and data were collected through questionnaire administration and field observations. The results show that waste is mostly generated from rubbish, representing 50%, followed by garbage and special waste at 30% and 11.7% respectively, while ashes/residues account for the least percentage at 8.3%. The major source of waste in the study area is household waste, which constitutes 56.7%, followed by commercial (26.7%), industrial (13.3%), and institutional sources (3.3%). Regarding waste collection methods, it was observed that dustbins serve as the most used means of waste collection in households (55%), followed by buckets (18.3%), drums (15%), and baskets (11.7%). The study also reveals that most respondents (65%) do not treat their waste before disposal. Additionally, 58.3% of respondents dispose of their refuse weekly, while 41.7% do so daily. The predominant method of waste handling in the area is open dumping (50%), followed by burning (33.3%), landfilling (10%), and composting (6.7%). Furthermore, 75% of the respondents reported having designated waste collection points. The study concludes that there is a lack of adequate institutional arrangements for solid waste disposal systems, and the prevalence of open dumping indicates a lack of public awareness about the implications of improper waste management. It is recommended that the government should increase the number of dumpsites to facilitate proper waste disposal and sponsor research into viable options for converting waste into wealth. Environmental Health Officers should be deployed to effectively monitor solid waste management practices and identify areas requiring urgent intervention. Additionally, intensive and consistent public enlightenment campaigns are necessary to foster attitudinal change toward waste disposal among the populace.

ASSESSING THE IMPACTS OF UNREGULATED SOLID WASTE DISPOSAL IN KADUNA CITY, NIGERIA

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ABSTRACT
Unregulated solid waste disposal presents a significant environmental and public health challenge in rapidly urbanizing cities such as Kaduna, Nigeria. This study evaluates the consequences of uncontrolled solid waste disposal across various zones within Kaduna City, focusing on its environmental, social, and health-related implications. Primary data were collected through field surveys, interviews, and structured questionnaires administered to residents, waste management officials, and health personnel. Secondary data were sourced from local environmental agencies and relevant literature. The study reveals that improper waste disposal practices contribute to frequent flooding, contamination of surface and groundwater, air pollution, and the proliferation of disease vectors. Additionally, socio-economic factors such as poor public awareness, weak enforcement of waste regulations, and inadequate infrastructure exacerbate the problem. The findings highlight the urgent need for integrated waste management strategies, community engagement, and institutional reform to mitigate the adverse impacts. Recommendations include enhancing waste collection systems, enforcing environmental laws, and promoting public education campaigns.
Keywords: Solid waste disposal, environmental impact, public health, urban management, Kaduna City, Nigeria, flooding, waste regulation.

CLOTH SIZE PREDICTION WITH AI: DECISION TREE

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ABSTRACT
The problem of high return is a major concern for most of the e-commerce industry. The people purchase online and return the cloth due to the problem of unfit. This increases the logistic cost in terms of transportation and the CO2 emission in the environment increases, which is not a sustainable practice. Artificial intelligence (AI) can be used to tackle this problem. The people who purchase from online retail store can predict the size of their cloth using machine learning algorithm and thus can decrease the problem of high return. In the research paper, a mathematical model to predict the size of the cloth using decision tree machine learning algorithm is developed. The users who purchase from online platform can predict the size of their cloth by providing the input in the model which are known to users for himself. The input variables used in the model are age, height and weight of the person. The node of the decision tree is decided based the entropy value. The data set used for this research paper is splitted into 70% training sets and 30% testing set. The developed model has good accuracy and hence it can save a lot of return of clothes. The coding for developed model is done in R. The developed model can be applied on various e-commerce platform like Myntra, Amazon, Fipkart etc. Thus, the developed AI model is a step towards sustainability which reduces the emissions from transportation sector by minimizing CO_2 emissions.
Keywords: Artificial intelligence, textile, machine learning, sustainability, supply chain

THE IMPACT OF THE MEDITERRANEAN DIET ON AUTOIMMUNE DISEASES: A SYSTEMATIC REVIEW AND ANALYSIS

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ABSTRACT

In this presentation, we explore the potential of the Mediterranean diet (MD) in the management of autoimmune diseases. Emerging evidence suggests that MD may play a significant role in reducing disease activity and modulating inflammatory processes. We present findings from a systematic review of recent studies, with particular focus on key dietary components such as dietary fiber, omega-3 fatty acids, polyphenols, resveratrol, vitamins, and essential micronutrients.Our analysis highlights how these components contribute to the anti-inflammatory and immunomodulatory effects observed in conditions like rheumatoid arthritis, systemic lupus erythematosus, and spondyloarthritis. While the results are promising, further research is needed to clarify the underlying mechanisms and to determine optimal dietary strategies.We also touch upon the importance of integrative approaches, combining diet with exercise and stress management, as a promising direction for future clinical applications. This presentation aims to offer new insights into how the Mediterranean diet can be effectively integrated into the therapeutic landscape of autoimmune disease care.

Keywords: Mediterranean diet, autoimmune diseases, rheumatoid arthritis, systemic lupus erythematosus, spondyloarthritis, dietary components, micronutrients, antioxidants, anti-inflammatory effects

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YENİ 1,3,4-TİYADİAZOL-HİDRAZON TÜREVİNİN SENTEZİ VE KARAKTERİZASYONU

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ÖZET

Heterosiklik bileşikler, sahip oldukları yapısal çeşitlilik ve fonksiyonel gruplara kolaylıkla bağlanabilmeleri sayesinde organik sentez alanında oldukça geniş bir uygulama alanına sahiptir. Bu bileşikler arasında yer alan 1,3,4-tiyadiazol halkası, iki azot ve bir kükürt atomu içeren beş üyeli bir heteroaromatik yapıdır. Bu yapı, sahip olduğu heteroatomların elektronik özellikleri ile hem yüksek reaktiviteye hem de çok yönlü kimyasal özelliklere sahiptir. Kimyasal kararlılığı sayesinde çeşitli organik sentezlerde ve özellikle ilaç tasarım çalışmalarında kritik bir öneme sahiptir. Hidrazon grubu ise, Schiff bazı karakterine sahip aromatik ya da heteroaromatik sistemlerle konjuge olabilen geniş bir reaktivite yelpazesine sahip fonksiyonel bir gruptur. Bu çalışmada, 1,3,4-tiyadiazol ve hidrazon gruplarını içeren yeni bir bileşik sentezlemeyi amaçlamaktadır. Sentez, beş aşamada gerçekleştirilmiştir: İlk olarak, 4-florofenil izotiyosiyanat ve hidrazin hidratın etanol ortamında tepkimesiyle N-(4-florofenil) hidrazinkarbotiyoamidin elde edilmiştir. Bu bileşik, karbon disülfür ve sodyum hidroksit varlığında halkalaşarak 5-((4-florofenil) amino)-1,3,4-tiyadiazol-2-tiyol yapısına dönüştürülmüştür. Sonraki adımlarda, sırasıyla kloroetilasetat ve hidrazin hidrat ile reaksiyonlar gerçekleştirilmiş, böylece asetohidrazid türevi sentezlenmiştir. Son aşamada ise, asetohidrazid öncül bileşik, 4-metoksibenzaldehit ile etanol ortamında geri soğutucu altında ısıtılarak reaksiyona sokulmuş; reaksiyon sonunda oluşan katı ürün süzülüp yıkandıktan sonra etanolden kristallendirilmiştir. Böylece, yeni bir tiyadiazol-hidrazon türevi başarıyla elde edilmiştir. Elde edilen bu yeni organik bileşiğin yapısı; ^{1}H-NMR, ^{13}C-NMR ve Elementel Analiz yöntemleri kullanılarak aydınlatılmıştır. Spektral veriler, bileşiğin yapısal bütünlüğünü doğrulamış ve sentezin başarıyla gerçekleştiğini göstermiştir.Bu çalışmadan elde edilen sonuç ile, konjuge sistemlere sahip, heteroaromatik karakterde yeni bir yapı organik sentez yoluyla hazırlanmış; saflaştırılarak analizlere uygun hale getirilmiştir. Elde edilen bu bileşik, ilerleyen süreçte biyolojik aktivitelerinin araştırılması amacıyla değerlendirmeye alınacaktır.

Anahtar Kelimeler: 1,3,4-tiyadiazol, hidrazon, organik sentez.

SYNTHESIS AND CHARACTERIZATION OF A NEW 1,3,4-THIADIAZOLE-HYDRAZONE DERIVATIVE

ABSTRACT

Heterocyclic compounds possess a wide range of applications in the field of organic synthesis due to their structural diversity and ability to easily bind various functional groups. Among these, the 1,3,4-thiadiazole ring, a five-membered heteroaromatic structure containing two nitrogen atoms and one sulfur atom, stands out. This scaffold exhibits high reactivity and versatile chemical behavior owing to the electronic properties of its heteroatoms. Its chemical stability makes it particularly valuable in various organic transformations and especially in drug design studies. On the other hand, the hydrazone group is a functional moiety with a broad reactivity profile, capable of forming conjugated systems with aromatic or heteroaromatic structures due to its Schiff base character.In this study, the aim was to synthesize a novel compound incorporating both 1,3,4-thiadiazole and hydrazone functionalities. The synthesis was carried out in five steps. First, N-(4-fluorophenyl) hydrazinecarbothioamide was obtained by the reaction of 4-fluorophenyl isothiocyanate with hydrazine hydrate in ethanol. This intermediate underwent cyclization in the presence of carbon disulfide and sodium hydroxide to yield 5-((4-fluorophenyl) amino)-1,3,4-thiadiazole-2-thiol. Subsequent reactions with chloroethyl acetate and hydrazine hydrate provided the acetohydrazide derivative. In the final step, the acetohydrazide intermediate was refluxed with 4-methoxybenzaldehyde in ethanol. The resulting solid product was filtered, washed, and recrystallized from ethanol to afford the target compound — a new thiadiazole-hydrazone derivative. The structure of this novel organic compound was elucidated using ^{1}H-NMR, ^{13}C-NMR, and elemental analysis techniques. The spectral data confirmed the structural integrity and successful synthesis of the compound.

As a result of this study, a new heteroaromatic compound with a conjugated system was successfully synthesized and purified for analytical purposes. The compound will be further evaluated for its potential biological activities in future studies.

Keywords: 1,3,4-thiadiazole, hydrazone, organic synthesis.

GREEN SYNTHESIS OF CALCIUM CARBONATE NANOPARTICLES ($CACO_3$NPS) FROM WASTE EGGSHELLS USING NEEM EXTRACT: A SUSTAINABLE APPROACH TO NANOMATERIAL PRODUCTION

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ABSTRACT
Eggshell disposal contributes to environmental pollution when not properly managed. When disposed as a landfill, it supports microbiological actions in the environment, it also posed a significant problem as it is directly related to public health. Eggshell landfills are responsible for waste contamination, pollution, and other environmental hazards. In this paper, calcium carbonate nanoparticles ($CaCO_3$NPs) were synthesized through green route from waste eggshells using neem plant extract (*Azadirachta indica*) offering a sustainable and eco-friendly approach to nanomaterial production. Waste eggshell predominately composed calcium carbonate, which is a valuable resource for nanotechnology, while the neem extracts act as a green reducing and stabilizing agent. The synthesized nanoparticles were characterized using X-ray diffraction (XRD), Fourier-transform infrared Spectroscopy (FTIR), Scanning electron microscopy (SEM), and Electron dispersive x-ray (EDX), which confirmed the formation of $CaCO_3$NPs. Major peaks of $CaCO_3$NPs were observed in the XRD pattern with an average crystallite size of 19.1nm, the particles were spherical and mainly composed of Ca (59.95%), O (33.07%), and C (6.98%) respectively as revealed by SEM and EDX. These $CaCO_3$NPs have potential applications in various fields, including biomedicine, material science and environmental remediation.
Keywords: waste eggshells, neem plant extract, nanoparticles, applications.

DEVELOPMENT AND ASSESSMENT OF NEW MX-106 HYDROXYQUINOLINE DERIVATIVES: 2D-QSAR ANALYSIS, MOLECULAR DOCKING, DYNAMICS SIMULATIONS, AND ADMET PREDICTIONS FOR TARGETED SURVIVIN INHIBITION

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ABSTRACT
The pressing need to develop and discover new inhibitors targeting survivin (BIRC5), one of the most tightly regulated genes in tumor cells, highlights the current focus of research. Survivin is a specific cancer biomarker and a promising target for anticancer drugs. This study details the methodology for designing a series of novel and selective survivin inhibitors, inspired by the hydroxyquinoline structure of our previously documented lead compound, MX-106.
Our research identified nine compounds predicted to have greater inhibitory potential than the most potent member of the set of the most potent compounds. In vitro, the assays confirmed these compounds' effectiveness in inhibiting the proliferation of MDA-MB-435 breast cancer cells. Additionally, their metabolic stability exceeded that of the most active molecule in the test set.Using 2D-QSAR methods, including multiple linear regression (MLR), multiple nonlinear regression (MNR), and artificial neural networks (ANN), along with molecular dynamics, molecular docking, and ADMET evaluation, we assessed 31 hydroxyquinoline derivatives of MX-106 as selective survivin inhibitors. Molecular docking simulations showed that compound C24 formed multiple hydrogen bonds with various residues, and a 100-ns molecular dynamics simulation confirmed its stability throughout, indicating its potential for further drug development.Based on molecular modeling insights, we designed nine new compounds (Pred1 to Pred9), predicted by MLR models to have strong survivin inhibitory activity. We recommend a thorough evaluation of the ADMET properties of these new compounds, positioning them as promising candidates for innovative anticancer agents targeting survivin inhibition, like MX-106.
Keywords: QSAR, tumor cells, Molecular Docking, Molecular dynamic, ADMET properties, selective survivin inhibitors, cancer, MX-106 hydroxyquinoline scaffold.

EVALUATING THE SAFETY AND TOXICITY PROFILE OF ASHWAGANDHA

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ABSTRACT
A common plant in Ayurvedic medicine, ashwagandha (Withania somnifera) has long been employed for its adaptogenic qualities. Its safety and toxicity profiles have been assessed by recent scientific investigations. There were no notable alterations in vital signs, hematological, or biochemical indicators, including thyroid function, in a randomized, double-blind, placebo-controlled research that involved 80 healthy adults who received 300 mg of ashwagandha root extract twice daily for eight weeks. Good tolerance was indicated by the lack of reported side events. A thorough analysis of 30 human trials found no significant adverse events and rather minor, temporary side effects like gastrointestinal distress and somnolence. Rats given dosages up to 800 mg/kg/day for 28 days in preclinical investigations did not exhibit any toxicity or notable histopathological alterations. These results imply that ashwagandha root extract is generally safe for ingestion; nevertheless, additional long-term research is advised to validate these findings.
Keywords: Safety Toxicity, Adaptogen, Clinical trials, Withania somnifera, Herbal medicine, Ashwagandha

VERIFICATION OF COUNTING OF LATTICES

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ABSTRACT
In 2013, Bhavale obtained an algorithm for counting of non isomorphic lattices containing r comparable reducible elements and having nullity k. Recently, Aware and Bhavale counted all non-isomorphic lattices on n elements containing up to four comparable reducible elements and having nullity up to three. In this paper, using the algorithm of Bhavale, we obtain in particular formulae of counting of lattices containing four comparable reducible elements and having nullity three. Further, we verify those formulae with the explicit formulae obtained by Aware and Bhavale.

IMPROVING HIGHWAY SAFETY WITH AUTOMATED LANE CHANGE USING SENSOR FUSION AND TRAJECTORY PLANNING

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ABSTRACT
This work introduces a new way to make a highway-only style automatic part of a focused hardware-software system meant for self-driving cars. The setup is made in line with Industry 4.0 ideas and the goals of the Energy Shift, focusing on green aspects, smart management, and being more efficient. With the help of many sensors, the system joins data to create a clear and active view of the car's surroundings. This complete understanding helps in accurate path planning so the self-driving car can identify objects nearby and safely carry out actions like changing lanes.The suggested framework looks at not just safety and reliability but also energy smartness and quick reactions. These factors are key for using self-governing systems in real-life situations, where changing easily and using little power are important. The structure can change how it drives from easy to tough traffic and from perfect to hard weather situations, so it helps cars run well and smoothly in many different places.It also enables secure interplay between self-driving cars and the environment, which comprises other vehicles, infrastructure, and road users. By offering a more connected and smart mobility ecosystem, it paves the way for the evolution of future smart transport systems. This study emphasizes that in locating ready-for-the-future autonomous driving technologies, there should be a mix of automation, environmental awareness, and system-level coordination.
Keywords: Autonomous driving, sensor fusion, trajectory planning, smart mobility, energy efficiency.

İKİ FARKLI METAL MALZEMENİN LAZER KAYNAĞINA ELVERİŞLİLİĞİNİN PROSES PARAMETRELERİNE BAĞLI OLARAK İNCELENMESİ

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ÖZET

Lazer ışın kaynağı, yüksek enerji yoğunluğu sayesinde geleneksel kaynak yöntemlerine kıyasla daha dar bir ısıdan etkilenen bölge (Heat Affected Zone, HAZ) oluşturarak, daha kaliteli ve hassas kaynak dikişleri elde edilmesine olanak tanımaktadır. Bu yöntem, otomotiv, gemi inşası ve hassas imalat sektörlerinde yaygın olarak kullanılmakta olup, farklı malzeme türlerinin birleştirilmesine de olanak sağlamaktadır. Lazer kaynak, temassız bir işlem olması ve yüksek odaklanma kabiliyeti sayesinde, özellikle küçük ve hassas parçaların birleştirilmesinde tercih edilmektedir. Bu çalışmada, AISI 304 paslanmaz çelik ve 16MnCr5 otomat çeliği malzemelerinin lazer kaynağı ile kaynaklanabilirliği, değişken lazer kaynak parametreleri altında incelenmiştir. Deneysel çalışmalarda üç farklı lazer kaynak gücü (90 W, 112.5 W, 135 W) ve üç farklı ilerleme hızı (2.5 mm/s, 5 mm/s, 10 mm/s) kullanılarak numuneler hazırlanmıştır. Kaynak işlemi sonrası numunelere çekme testi uygulanarak mekanik performansları değerlendirilmiştir. Elde edilen sonuçlar, kaynak gücü ve ilerleme hızının birleşme mukavemeti üzerinde belirgin etkileri olduğunu göstermektedir. Yapılan çekme testi sonucunda, 112.5 W güç ve 5 mm/s hız değerlerinde elde edilen kaynak dikişi, 2160 N'luk maksimum yük taşıma kapasitesiyle en yüksek dayanımı göstermiştir. Ancak ilerleme hızının artmasıyla kaynak nüfuziyetinde ve bağlantı kalitesinde azalma meydana geldiği gözlemlenmiştir. Elde edilen bulgular, lazer kaynak parametrelerinin optimize edilmesiyle malzeme birleştirme performansının artırılabileceğini ortaya koymaktadır. Bu bulgular, farklı malzeme çiftlerinde benzer parametrelerin kullanılabilirliği konusunda da önemli bir referans sunmaktadır. Gelecekte yapılacak mikro yapı analizleri ve termal görüntüleme destekli çalışmaların, lazer kaynak süreçlerinin daha derinlemesine anlaşılmasına katkı sağlayacağı değerlendirilmektedir.

Anahtar Kelimeler: Lazer kaynak, Kaynaklanabilirlik, Kaynak Parametreleri

INVESTIGATION OF THE SUITABILITY OF TWO DIFFERENT METAL MATERIALS FOR LASER WELDING DEPENDING ON PROCESS PARAMETERS

ABSTRACT

Laser beam welding, with its high energy density, creates a narrower Heat Affected Zone (HAZ) compared to conventional welding methods, enabling the production of higher-quality and more precise weld seams. This method is widely used in the automotive, shipbuilding, and precision manufacturing industries, and it also facilitates the joining of dissimilar materials. Due to its non-contact nature and high focusing capability, laser welding is particularly preferred for joining small and delicate components.In this study, the weldability of AISI 304 stainless steel and 16MnCr5 free-cutting steel using laser welding was investigated under varying laser welding parameters. In the experimental work, samples were prepared using three different laser powers (90 W, 112.5 W, 135 W) and three different travel speeds (2.5 mm/s, 5 mm/s, 10 mm/s). After welding, tensile tests were applied to evaluate the mechanical performance of the specimens. The results demonstrated that both laser power and welding speed have significant effects on joint strength. Among the tested conditions, the weld produced at 112.5 W power and 5 mm/s travel speed showed the highest load-bearing capacity, reaching a maximum load of 2160 N. However, it was observed that increased welding speed led to reduced penetration and bonding quality.These findings indicate that optimizing laser welding parameters can significantly enhance material joining performance. Furthermore, they provide a valuable reference for the application of similar parameters in different material combinations. Future studies supported by microstructural analysis and thermal imaging techniques are expected to contribute to a deeper understanding of laser welding processes.

Keywords: Laser welding, Weldability, Welding Parameters

THE COLLAPSE OF INDIVIDUALISM: EXPLORING THE DANGERS OF ISOLATION IN THE QUEST FOR PEACE IN NIYI OSUNDARE'S NOT MY BUSINESS

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ABSTRACT
This paper interrogates the theme of isolation and the consequences of individualism in Niyi Osundare's politically charged poem, *"Not My Business."* A critique of oppression and authoritarianism, the poem captures the adverse effects personal detachment when systemic injustice is the order of the day. Relying on postcolonial and social responsibility theories, this study examines how Osundare challenges the practice of individuals keeping mum so far they are not directly affected by societal injustice. With qualitative textual analysis, the research observes the poet's strategic use of repetition, irony, and narrative progression to demonstrate the gradual collapse of the poetic persona's sense of safety. From the close reading, it emphasises the poem's literary devices and its thematic resonance with the socio-political context of postcolonial Nigeria. That Osundare's poetic voice ultimately moves from apathy to awakening, resonating the belated recognition of collective vulnerability when one remains isolated in pursuit of personal peace. Findings reveal a serious critique of individualism, presenting it as a fragile illusion that scatters when oppressive systems ultimately land on the seemingly unaffected. The poem is a microcosm of societies where silence encourages tyranny. Hence, *"Not My Business"* transcends its Nigerian context to present a universal message that silence in the face of injustice is complicity, and peace achieved through isolation is unsustainable. It equally calls for a renewed ethic of communal vigilance and solidarity as the only antidote to systemic oppression.
Keywords: Individualism, Communal Solidarity, Communal Ethics, Social Injustice, Public Moralist

FUNGAL DIVERSITY OF SOILS OF PINE FOREST

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ABSTRACT
The diversity of fungi from soil represents the fertility as they play a major role as deteriorators, degrading organic material to compost. Thus, enhancing the mineral content including Nitrogen in soil. However, in special environment like the forest occupied by monoculture plants may serve as a unique ecosystem where they may alter the presence of fungi. One such example is the Pine forest located in Kodaikanal, the hills of Palani range in the State of Tamil Nadu, India. The plants were nearly of 120 years old and the most of the litter found in the soil belongs to the needles of pine. This made an interest to study the fungal flora of the soils of this environment. Nearly 30 samples were collected and serially diluted for isolating the fungal colonies using Potato Dextrose Agar as the medium. A total of 27 different species of fungi were recorded. Among them 4 belongs to Mucoraceous fungi, 2 to Ascomycota, 2 to Coelomycetes and all the remaining species belongs to Deuteromycetes. Among the genera, the genus *Aspergillus* alone is represented by 8 species followed by *Penicillium* with 2 species. All other genera are represented by single species each. Among the species, *Gliocladium roseum* was found dominant followed by *Phoma* sp. The results in detail will be discussed.
Keywords: Soil fungi, Fungal diversity, Pine forest, *Gliocladium roseum*, *Phoma* sp.

HASSE DIAGRAMS OF BASIC BLOCKS CONTAINING 4 COMPARABLE REDUCIBLE ELEMENTS AND HAVING NULLITY FIVE

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ABSTRACT
In 1940 Birkhoff raised the open problem enumerating all finite posets / lattices which are uniquely determined (up to isomorphism) by their diagrams, considered purely as graphs. In 2020, Bhavale and Waphare introduced the concepts of fundamental basic block and basic block, associated to posets / dismantlable lattices.Further, they have provided the formulae of the number of non- isomorphic fundamental basic blocks as well as basic blocks, containing r comparable reducible elements and having nullity l.In this paper, using the counting of fundamental basic blocks we obtain and draw the Hasse diagrams of the basic blocks containing four comparable reducible elements and having nullity five.

HASSE DIAGRAMS OF BASIC BLOCKS CONTAINING FOUR COMPARABLE REDUCIBLE ELEMENTS AND HAVING NULLITY FOUR

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ABSTRACT
In 1940 Birkhoff raised the open problem of enumerating of all finite posets / lattices which are uniquely determined (up to isomorphism) by their diagrams, considered purely as graphs.
In 2020 Bhavale and Waphare introduced the concepts of fundamental basic block and basic block associated to posets / dismantlable lattices.Further, they have provided the formulae of the number of non-isomorphic fundamental basic blocks as well as basic blocks, containing r comparable reducible elements and having nullity l.In this paper, using the counting of fundamental basic blocks, we obtain and draw the Hasse diagrams of the basic blocks containing four comparable reducible elements and having nullity four.

MATHEMATICAL MODELING OF HIV/AIDS INVESTIGATING THE EFFECT OF INCONSISTENT TREATMENT WITH NONLINEAR INCIDENCE

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ABSTRACT
The human immunodeficiency virus (HIV) and acquired immune deficiency virus (AIDS) pandemic continues to pose significant public health challenges. This study develops a mathematical model to investigate the impact of inconsistent treatment on HIV transmission dynamics. The model incorporates a saturated incidence rate, which accounts for the non-linear effect of susceptible individuals on disease transmission. The results show that inconsistent treatment can significantly affect disease prevalence and transmission dynamics. The model's findings highlight the impact of inconsistence treatment on HIV transmission dynamics and provide insights for the development of effective intervention strategies. The study contributes to the understanding of HIV transmission dynamics and the role of treatment in controlling the disease.
Keywords: HIV/AIDS, Nonlinear Incidence, Inconsistent treatment, Transmission

EFFİCACY OF CASHEW BASED COMPOST ON *FUSARİUM* WİLT AND FRUİT YİELD OF TOMATO (*SOLANUM LYCOPERSİUM* L.)

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ABSTARCT
Tomato is often attacked by wilt caused by *Fusarium oxysporum*. Cashew based compost is known to have a fungicidal effect in the control of plant pathogens. The present experiment was aimed at determining the effect of soil amendment with cashew based compost on *Fusarium* wilt and fruit yield of two tomato varieties (Ibadan local and Roma VF). The experiment was a 2 x 4 factorial experiment fitted into a Randomized Complete Block design with three replicates. The experiment was carried out on the field in 2022 and 2023 at Teaching and Research Farm of Federal University of Agriculture, Abeokuta. The cashew based compost was applied at 0, 6, 12 and 18 tons/ha. Results showed that Roma VF treated with cashew based compost at 18 tons/ha in 2022 and 2023 had the lowest (0.00%) disease incidence. The disease severity was significantly ($p \leq 0.05$) lower (0.00) in 2022 and 2023 when Roma VF was treated with cashew based compost at 18 tons/ha. Also, Roma VF treated with 18 tons/ha in years 2022 and 2023 significantly produced higher (23.1 tons/ha and 10.6 tons/ha, respectively) fruit yields. The study concluded that application of compost at 18 tons/ha reduced *Fusarium* wilt and increased the fruit yield of tomatoes.
Keywords: Tomato, *Fusarium oxysporum*, fungicidal, cashew based compost.

ADVANCING AGRICULTURAL SUSTAINABILITY: THE ROLE OF NANO FERTILIZERS IN ENHANCING FOOD QUALITY AND SAFETY

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ABSTRACT
Nanotechnology has emerged as a transformative tool in agriculture, particularly through the development of nano fertilizers. These fertilizers, engineered at the nanoscale, offer enhanced efficiency in nutrient delivery, improving plant growth while minimizing environmental impact. Due to their unique properties such as increased surface area, solubility, and controlled release, nano fertilizers can optimize nutrient absorption by plants, resulting in higher crop yields and reduced fertilizer wastage. This precision not only contributes to sustainable agricultural practices but also addresses the challenges of excessive chemical runoff and soil degradation.The application of nano fertilizers also holds significant implications for food quality and safety. By promoting healthier and stronger crops, nano fertilizers can lead to the production of higher-quality food with reduced pesticide and chemical residue. Furthermore, the precise nutrient release helps to enhance the nutritional profile of crops, ensuring better food security and quality for consumers. Nano fertilizers can also play a role in reducing contaminants that typically arise from conventional fertilizers, making the food supply safer for public consumption.This paper explores the interconnectedness of nano fertilizers, food quality, and safety, emphasizing the potential of nanotechnology to revolutionize agricultural practices while ensuring the integrity of the food chain. By examining their impact on crop productivity, nutritional content, and overall food safety, the study calls for further research to ensure the safe integration of nano fertilizers into agricultural systems for the benefit of both the environment and public health.
Key words: Nano Fertilizers; Sustainable Agriculture; Nanotechnology; Food quality; Food safety.

PHENOLIC PROFILE AND ANTIMICROBIAL ACTIVITY OF *ROSMARINUS OFFICINALIS* IN DIFFERENT ALGERIAN REGION

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ABSTRACT
Plants were always a part of the everyday life of the man, because he uses it to look after itself for a long time. Essential oil of *Rosmarinus officinalis* were used during centuries as remedies for the human diseases because they contain components of therapeutic value. Oil is located in various parts of plants (flowers, sheets, barks, wood, fruits, seeds … etc.), for the obtaining of these gasolines there are several variable techniques.The extraction of this one by the hydrodistillation method revealed average yields varying between 0.05 and 1.52% in Algeria and between 0.48 and 1.9% in the world.GC-MS analyzes indicated that Algerian essential oil was dominated by the following components: camphor, eucalyptol, α-pinene, camphene, for the world, was dominated by the:1-8 cineol, camphre and p-cymene.The aromatogram and the MIC's determination showed that rosemary oil possesses a great activity against both bacteria and fungi. Among the most sensitive bacteria we cite the species *Staphylococcus aureus*, *Bacillus subtilis* and *Shigella* sp., while among the fungi there are the genera *Candida* and *Trichophyton*. In contrast, *Pseudomonas aeroginosa*, *Aspergillus flavus* and *Penicillium islandicum* have been shown to be resistants to the action of the essential oil.
Keywords: *Rosmarinus officinalis*, essential oil, yield, GC-MS, antimicrobial activity, aromatogram, MIC

MOLECULAR CHARACTERİZATION AND DETERMINATION OF AMYLASE-PROTEASE ACTIVITY OF BACTERIAL ISOLATES FROM SEPTIC TANK

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ABSTRACT
Septic systems represent complex and dynamic microbial habitats rich in diverse bacterial communities capable of producing industrially important enzymes. These environments, often overlooked in microbiological research, serve as reservoirs for novel microbial strains with potential applications in biotechnology. In recent years, the growing demand for eco-friendly and cost-effective enzyme production has driven the exploration of alternative microbial sources. Amylase and protease enzymes are widely used in various industries including food processing, textiles, detergents, and wastewater treatment. Therefore, the discovery of new bacterial strains with high amylolytic and proteolytic capacities is of significant interest.
In this study, bacterial isolation was directly performed from septic samples using conventional cultural methods. The colonies exhibiting different morphologies were initially characterized using morphological and biochemical techniques. Molecular identification was carried out via 16S rRNA gene sequencing to accurately classify the isolates at the genus and species levels. Based on the sequencing results, isolates belonging to the genera *Acinetobacter sp.*, *Shewanella sp.* and *Serratia sp.* were identified.Enzyme activity assays were performed on solid media to evaluate the amylase and protease production capabilities of each isolate. Photographic documentation was conducted for all bacterial isolates. Future studies are planned to investigate the commercial potential of the isolates showing significant enzymatic activity.
Keywords: Septic, amylase, bacterial isolation
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CuO/PS/nSi SCHOTTKY DİYOT YAPILI NON-ENZİMATİK GLİKOZ SENSÖRLER

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ÖZET

Bu çalışmada, n – tipi tek kristal silisyum (cSi) yüzeylerinde sabit akım yoğunluklu ve beyaz ışık aydınlatması eşliğinde, HF asit temelli bir çözelti kullanılarak elektrokimyasal aşındırma (anodizasyon) yöntemi ile gözenekli silisyum (GS) katmanı oluşturulmuştur. Farklı anodizasyon sürelerinde üretilmiş GS tabanlı Metaloksit/GS/nSi diyot yapılarının sulu D – glikoz çözeltilerinin hipoglisemi ve hiperglisemi konsantrasyon bölgeleri için glikoz sensor performansları incelenmiştir. Gözenekli silisyum tabakaların yapısal ve fiziksel karakterizasyonu yapılmıştır. Oluşturulan Schottky diyot yapılarının üzerinde herhangi bir dış kaynak kullanılmadan kısa devre akımı (Isc) ve açık devre gerilim (Voc) değerlerinin glikoz çözelti konsantrasyonuna bağlı değişimleri incelenmiştir. Metaloksit yapı olarak bakıroksit (CuO) kullanılmış olup, bu yapının katalitik etkisi değerlendirilmiştir. CuO/GS/nSi yapıları için Isc ve Voc değerlerinin değişiminde, CuO katmanın katalitik etkisi ve GS'un gözeneklilik boyutunun etkili olduğu görülmüştür. Özellikle CuO/GS/nSi diyot örneklerinde Isc değerlerinin, metal oksit kaplı olmayan GS/nSi diyot yapılarına kıyasla arttığı belirlenmiştir.

Anahtar Kelimeler: Gözenekli Silisyum, CuO, Glikoz Sensör

Bu çalışma Yıldız Teknik Üniversitesi Bilimsel Araştırma Projeleri Koordinasyon Birimince FDK-2024-6247 numaralı proje tarafından desteklenmiştir.

CuO/PS/nSi SCHOTTKY DIODE STRUCTURED NON-ENZYMATIC GLUCOSE SENSORS

ABSTRACT

In this study, a porous silicon (PS) layer was formed on n-type single crystal silicon (cSi) surfaces by electrochemical etching (anodisation) using an HF acid based solution under constant current density and white light illumination. The glucose sensor performances of PS - based metal oxide/PS/nSi diode structures fabricated at different anodisation times were investigated for hypoglycaemia and hyperglycaemia concentration regions of aqueous D - glucose solutions.The structural and physical characterisation of the porous silicon layers has been carried out. The variations of short circuit current (Isc) and open circuit voltage (Voc) values depending on glucose solution concentration were investigated without using any external source on the Schottky diode structures. Copper oxide (CuO) was used as metal oxide structure and the catalytic effect of this structure was evaluated. It was observed that the catalytic effect of the CuO layer and the porosity size of the PS were effective in the change of the Isc and Voc values for the CuO/PS/nSi structures. In particular, CuO/PS/nSi diode samples were found to have increased Isc values compared to PS/nSi diode structures without metal oxide coating.

Keywords: Porous Silicon, CuO, Glucose Sensor

This study was supported by Yıldız Technical University Scientific Research Projects Coordination Unit, project number FDK-2024-6247

MY PATIENT HAS SIGNS OF PSORIASIS: HOW CONCERNED SHOULD I BE AND WHAT SHOULD I DO?

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ABSTRACT
Background Restoration of the dysbiotic gut microbiome has emerged as a promising aid and a better therapeutic approach.Objectives New evidences suggest that the microbiome may play a pathogenic role in psoriatic disease. The aim of the present project is to investigate whether a dietary intervention could ameliorate the clinical manifestations and modulate the gut microbiota of individuals with psoriasis.Materials and methods Nutrition plays an important role in the development of psoriasis and it can modulate microbiome composition.Results Among environmental factors, diet plays a central role therefore incorrect nutritional habits and excessive body weight can increase clinical symptoms or even trigger the disease. Such diet-based and nutraceutical approaches to targeting the microbiome may produce a milder side effect profile than current systemic medications. Thus, interventions aimed at the microbiome may be a valuable adjunct for preventing or managing psoriatic disease and its comorbidities.Conclusion Nutrition plays an important role in the development of psoriasis and its comorbidities. Ultimately, a better understanding of the psoriatic microbiome can lead to the development of new therapeutic modalities that target the shifting microbiota. Thus, interventions aimed at the microbiome may be a valuable adjunct for preventing or managing psoriatic disease and its comorbidities
Keywords: psoriasis, microbiome, microbiota, Deniplant nutritional therapy

PPLICATIONS OF LAPLACE AND INVERSE LAPLACE TRANSFORMS IN ELECTRICAL ENGINEERING FOR ANALYZING AND SOLVING CIRCUIT DIFFERENTIAL EQUATIONS

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ABSTRACT
Laplace and inverse Laplace transforms are powerful mathematical tools widely used in electrical engineering for analyzing and solving circuit differential equations. These transforms provide a systematic approach to converting complex time-domain differential equations into algebraic expressions in the Laplace domain, simplifying the process of solving circuit-related problems. In electrical engineering, circuit analysis often involves solving differential equations that describe the behavior of circuit components such as resistors, capacitors, and inductors. The Laplace transform allows engineers to convert these equations into the frequency domain, where algebraic manipulation becomes more manageable. This method is particularly beneficial in the analysis of transient and steady-state responses of circuits. For instance, the Laplace transform is extensively used in the study of RLC circuits, signal processing, and control systems. Once the algebraic equation is solved in the Laplace domain, the inverse Laplace transform is applied to retrieve the time-domain solution. This approach facilitates the determination of circuit responses to various inputs, including step, impulse, and sinusoidal signals. Engineers use this technique to design stable circuits, optimize performance, and predict system behavior under different operating conditions. Overall, Laplace and inverse Laplace transforms are essential in electrical engineering, providing an efficient method to solve circuit differential equations, analyze system dynamics, and enhance circuit design. These mathematical tools enable engineers to gain deeper insights into electrical circuits, improving functionality and reliability in practical applications.
Keywords: circuit analysis , signal processing , control systems, system dynamics

INTEGRATING TRADITIONAL AND MODERN MEDICINE IN HEALTHCARE SYSTEM

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ABSTRACT
In 1978, a World Health Organization official advocated for traditional medicine in developing nations. Since then, there has been a growing interest among these nations in incorporating traditional medicine into their national healthcare systems. Incorporating traditional medicinal plant knowledge with current pharmaceutical research holds great promise for the creation of innovative and state-of-the-art modern medicine. The indigenous and traditional usage of medicinal plants can shed light on how to improve medication development processes, according to the investigation. The medicinal uses and efficacy of herbal treatments are often well-grounded in traditional wisdom that has been refined over many years. We will also be looking at technologies and procedures that can help bring conventional procedures up to date with contemporary medicine more quickly. To better understand how conventional medicines work, researchers are turning to systems biology, metabolomics, and high-throughput screening techniques. Traditional medicines can be confirmed to work and their active components identified for future studies if their safety, effectiveness, and chemical makeup can be documented. It goes on to say that a more holistic approach that incorporates the best of both traditional and modern medicine can improve patient care. The present work adds to the expanding body of literature on healthcare integration by shedding light on the challenges of combining old and new medical practices and by suggesting avenues for further study and policymaking in this area.
Keywords: Traditional medicine, pharmaceutical research, Medicinal plants, Modern medicine, Metabolomics.

RELATION BETWEEN DAMAGE RATE & CONNECTION LOOSENING PERFORMANCE: EVALUATION OF CALCULATION & VALIDATION

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Abstract
Tie rod is part of the steering mechanism in vehicle which connects steering rack to the knuckle. These components are loaded in vehicle by dynamic and static loads during their working conditions. Tie rod's endurance is validated under dynamic load conditions to simulate real time load signals & profiles which are collected from different road conditions. In this content, variated misuse load collectives had been investigated to correlate the connection loosening performance. The damage rate severities of these collectives are calculated as 1 time, 3.5 times and 3 times by using Wöhler equation. At first, finite element analysis has been used to calculate the plasticization & screw connection loosening behavior. The FEA result clearly says that there is a correlation between damage rate and loosening behavior of the screw connection. Then, three different kinds of load collective have been applied for real time tests. Expectation was linear correlation between load collective damage rates and loosening performance on screw connections. Nevertheless, the test result shows us that loosening occurrence has been seen at the beginning of the test and the remained pretension in the connections are stayed similar until end of the test. When we bring all the data to the table, the highest damage rate has not created the highest loosening rate on the knuckle-tie rod screw connection. The highest loosening has been occurred on 1 time calculated load collective.As a conclusion, theory says that when damage rate is increased, loosening rate increases. However, Investigation proved that there is not always a linear relation between damage rate & loosening evaluation. Damage rate is calculated by using load and cycle. For better pre-development & estimation, not only cumulative damage rate should be taken into account, also cycle effects should be taken into account individually during calculation-load profile creation phases considering the loosening behavior.

Keywords: Tie rod, Damage rate, Load, Cycle, Screw connection, Loosening, FEA

DATA ENVELOPMENT ANALYSIS APPLICATION IN TEXTILE INDUSTRY

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ABSTRACT

The world we live in is rapidly developing and people's needs are increasing day by day. For this reason, the number of businesses established to meet people's needs is also increasing. This situation increases cooperation among businesses and also leads to competition. Businesses that are successful in a competitive environment are those that can use their resources most efficiently. These businesses transform their resources (inputs) into products (outputs) in order to achieve the goals they set. Evaluating the performance of businesses in a certain period of time includes investigating how effective they are in transforming the inputs they use into outputs. In performance evaluation, it is examined whether businesses achieve the highest output level from the inputs used or whether they can reach a certain output level with the least amount. For this reason, performance evaluation studies are of great importance for businesses. Various methods are used to evaluate performance and Data Envelopment Analysis (DEA) is at the forefront among these methods. In this study, concepts such as performance, effectiveness, efficiency and productivity are discussed and how important these are for businesses are evaluated. In this study conducted for the textile sector, 6 companies will be evaluated and the data will be obtained from the Chamber of Commerce and Industry website. 'Lindo Package Program' will be used for performance measurement and evaluation.

Keywords: Data envelopment analysis, iron and steel efficiency, production sector, efficiency

Preparation and Biodistribution of ^{90}Y-EDTMP for Bone Seeking Therapeutic Agent

PREPARATION AND BIODISTRIBUTION OF ^{90} Y-EDTMP FOR BONE SEEKING THERAPEUTIC

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ABSTRACT
The preparation of ^{90}Y-EDTMP is described using Y-90, which was obtained from neutron irradiation of Y_2O_3 as well as from a laboratory scale organic resin-based ^{90}sr→^{90}y generator. Various parameters such as ligand and metal molar ratio, pH and incubation time were standardized to get maximum labelling yield. All experiments were carried out at room temperature (22± 2ºC) while volume of reaction mixture was fixed 2mL. The biodistribution of no-carrier-added and carrier-added ^{90}Y-EDTMP complexes in rats was also evaluated. The results indicate that ^{90}Y (carrier-added)-EDTMP may be an effective bone pain palliation agent because of its rapid blood clearance, greater uptake in bones and little absorption in soft tissues.
Keywords: Yettrium-90; Strontium-90/Yttrium-90 generator; EDTMP; Biodistribution

SMALLHOLDER FARMERS' AWARENESS OF BRUCELLOSIS IN SMALL RUMINANTS IN URBAN AREAS OF JAKARTA, BEKASI, AND BOGOR, INDONESIA

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Abstract
Brucellosis is a neglected zoonotic disease caused by *Brucella militenses.* The disease poses economic and public health concerns, particularly in small ruminant production systems. This study aimed to assess the demographic profile, farm characteristics, and awareness of brucellosis among smallholder farmers in the urban areas of Jakarta, Bekasi, and Bogor,

Indonesia. A cross-sectional survey was conducted in October to November 2023 among 58 goat and sheep farmers using structured interviews. The majority of respondents were male (89.7%, $p < 0.001$), significantly skewed toward aged between 40 and 55 years (50%, $p = 0.014$), and mostly had senior secondary education (32.8%). Urban livestock farming was primarily intensive (81%) and based on permanent housing (74.1%), with flock sizes varying from small to large. Sheep were the most commonly raised species (58.6%), followed by mixed herds (24.1%). Alarmingly, none of the farmers were aware of brucellosis. Risk-prone practices included 77.6% handling aborted fetuses without protection and 5.2% consuming raw milk. Although 81% isolated sick animals, 41.4% reported reproductive health problems, and 24 farmers observed abortion cases within their herds. However, only 27.6% disposed of aborted materials through burial. These findings highlight a significant lack of awareness and risky practices that could facilitate the transmission of brucellosis between animals and humans. Strengthening education and disease awareness among urban smallholder farmers is crucial for reducing zoonotic risks and improving small ruminant health management.

Keywords: brucellosis, diseases awareness, smallholder farmers, small ruminants, urban livestock systems.

EPIDEMIOLOGICAL PROFILE AND PUBLIC HEALTH RISKS OF ZOONOTIC DISEASES IN ASSAM, INDIA: A ONE HEALTH PERSPECTIVE

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ABSTRACT

Assam, a biodiversity-rich region in Northeast India, is facing an escalating burden of zoonotic diseases, primarily driven by rapid urbanization, unregulated livestock practices, and increasing human–wildlife interactions. This study investigates the prevalence and distribution of key zoonotic infections—Japanese Encephalitis, Scrub Typhus, Leptospirosis, Brucellosis, and Rabies—across twelve districts of Assam, utilizing secondary data derived from government health surveillance reports, medical and veterinary records, and laboratory-confirmed case registries spanning 2022 to 2024.Japanese Encephalitis emerged as the most dominant zoonosis, accounting for 28.6% of the total reported cases, followed by Scrub Typhus (24.1%), Leptospirosis (18.3%), Brucellosis (15.7%), and Rabies (13.3%). Spatial analysis using Geographic Information System (GIS) tools revealed significant clustering of cases in low-lying flood-prone areas, where anthropogenic activities and seasonal human–animal interactions intensify. Available molecular surveillance data suggest region-specific adaptation in Leptospira interrogans and Brucella abortus strains, highlighting the influence of environmental and occupational risk factors such as paddy cultivation, inadequate sanitation, and close livestock contact on transmission dynamics. The study emphasizes the urgent need for a comprehensive One Health framework that integrates surveillance, cross-sectoral collaboration, and targeted public health interventions. Strengthening veterinary services, advancing diagnostic capabilities, and promoting community-level health education are essential strategies to mitigate zoonotic threats and enhance ecosystem and population health resilience in Assam.

Keywords: Zoonotic diseases, Assam, Japanese Encephalitis, Brucellosis, Leptospirosis, One Health, GIS, epidemiological mapping, secondary data analysis, transmission dynamics

SPECIES DISTRIBUTION OF CLADOCERANS IN THE SEFERIHISAR- AKARCA BAY (AEGEAN SEA)

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ABSTRACT
Cladocerans are an important group of marine zooplankton and knowledge of the seasonal distribution of this group provides fundamental insights into trophic interactions, ecological dynamics and response to environmental stress, making it a valuable component for monitoring marine ecosystems.The study was carried out seasonally at three stations in Seferihisar Akarca Bay in 2020. Zooplankton samples were collected vertically using a WP-2 plankton net with a mesh size of 200 µm. Although the total abundance of cladocerans did not reach very high values, it varied between 6.27 ind./m³ at station S1 in November and 1143 ind./m³ at station S3 in August. No individuals of cladocerans were found in February. A total of five species—*Penilia avirostris*, *Evadne spinifera*, *Pseudoevadne tergestina*, *Pleopis polyphemoides*, and *Podon intermedius*—were found throughout the study. The abundance of cladoceran species showed significant seasonal and spatial differences. *Evadne spinifera* had the highest abundance during the warmer periods and was observed as the dominant species. Only *Penilia avirostris* reached its highest abundance at station S5 in August. The abundance of other cladoceran species were generally low and dont show a clear seasonal trend. The data obtained in this study provide important information about the seasonal dynamics of cladoceran communities and the responses of these species to environmental conditions.
Keywords: Cladocerans, Seferihisar-Akarca Koyu, Aegean Sea, Abundance, Species composition

RECENT SAMPLING TECHNIQUES AND ANALYTICAL APPROACHES IN MARINE ZOOPLANKTON RESEARCH

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ABSTRACT

Zooplankton constitutes a vital component of the pelagic food web in marine ecosystems. Accurate estimation and measurement of these organisms are essential for ecological studies. In recent years, technological advancements have significantly enhanced zooplankton research by increasing the sensitivity, precision, and scope of sampling and analytical methods. In this study, traditional zooplankton sampling and examination methods are reviewed alongside modern technological tools and techniques developed in recent years.Classical net-based systems, including Bongo nets, WP-2 nets, and advanced multiple opening/closing net systems such as MOCNESS and BIONESS, are extensively utilized for both horizontal and vertically stratified sampling. In addition, Niskin bottles, Rosette sampling equipment, and plankton pumps enable sampling at specific depths within the water column.For zooplankton examination post-sampling, conventional microscopic methods are increasingly supported by semi-automated imaging systems such as FlowCam and ZooScan, which facilitate rapid morphological analyses. Molecular approaches, particularly environmental DNA (eDNA) analyses, have emerged as robust methods for biodiversity monitoring, offering significant advantages for detecting cryptic and rare species.In situ observational capabilities have also advanced substantially due to the integration of Acoustic Doppler Current Profilers (ADCPs) and scientific echo sounders, allowing efficient estimation of zooplankton biomass and spatial distribution. Autonomous platforms such as Zooglider, Continuous Plankton Recorder (CPR), and Underwater Vision Profiler (UVP) provide real-time data on the distribution of planktonic organisms. These technological innovations complement traditional methodologies, generating comprehensive, multidimensional ecological datasets.In conclusion, integrating conventional sampling and analytical methods with modern technologies enables rapid, detailed, and comprehensive data acquisition and enhances the understanding of zooplankton community dynamics. This study advocates interdisciplinary approaches to ensure accurate, reliable, and scalable assessments of marine ecosystems.

Keywords: Zooplankton, Sampling technologies, FlowCam, ZooScan, Zooglider, eDNA, Acoustic Monitoring

POLUTION OF SMALL PARKS IN THE URBAN AREA WITH DOG PARASITES

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ABSTRACT

Small parks integrated into urban units make up the largest number of park units in cities. Those parks are the main place where children play and are resting places for city people and places where dog owners walk its pets. That places dogs permanent pollute with their excrement. Dog feces besides its unpleasant appearance and odor present high epidemiological risk because dogs are carriers and hosts of a numerous zoonotic parasites species which eggs were eliminated by feces. Controls of parks and green areas with dog parasite contamination in the Belgrade area were carried out continuously from 1993 to 2023. During the investigation of parasitic contamination of parks, the emphasis was mostly placed on central parks and green areas in the city, neglecting these small green oases. Here we present the results of the contamination of small parks in the central city municipalities in the period 2021-2023. Soil samples from 19 small parks were examined with flotation methods by Stoll and Richardson-Kendell and by modificated flotation methods by Pavlovic. Determination of parasite eggs was made on the basis of their morphological characteristics. Parasites contamination were detected at 65.08% soil samples. *Ancylostomidae spp*. were found at 51.44% soil samples, *Toxocara canis* at 36.88% , *Dipyllidium caninum* at 29.67%, *Toxascaris leonina* at 11.23%, *Strongyloides stercoralis* at 2.37%, *Taenia* -type helminths at 1.71%. and *Trichuris vulpis* at 1.19%. If we compare the results of the research with the findings of contamination of large park areas, it can be seen that these are significantly more contaminated. In central city parks, this contamination amounted to 44.08% compared to 65.08% in small parks.

Key Words: pet dogs, helminths, small parks, polution

CONSTRUCTED WETLANDS AS ECO-TECHNOLOGIES FOR DECENTRALIZED WASTEWATER MANAGEMENT

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ABSTRACT
Wetlands, whether natural or man-made, are gaining increased recognition as viable systems that are both economically sound and environmentally friendly for treating wastewater. These ecosystems remove contaminants by using the physical, chemical, and biological means as enhanced by the synergistic interphase among wetland vegetation, microbial communities, and substrates, to employ waste removing agents. The paper outlines widely known applications of constructed wetlands (CWs), such as free water surface flow (FWS), horizontal subsurface flow (HSSF), and vertical flow (VF), in treating a variety of wastewaters, ranging from municipal to industrial and agricultural effluents. The process mechanisms on which sedimentation, filtration, microbial degradation, plant uptake, and adsorption rely, among others, are discussed in terms of their effectiveness for reducing BOD, COD, nutrients (nitrogen and phosphorus), pathogens, and heavy metals from wastewater. This paper also critically examines some design parameters (hydraulic retention time, organic loading rate, vegetation type) and evaluates performance efficiencies with regards to case studies drawn from climatic zones. Integrating CWs into decentralized wastewater treatment frameworks thus opens up a low-energy, low-maintenance option for eco-conservation purposes and sustainable development at the global level.
Keywords: Wetlands, wastewater, BOD, COD, pathogens, heavy metals, sustainable development, contaminants, agricultural effluents, industrial effluents, environmentally friendly.

IMPROVEMENT OF POLYPROPYLENE (PP)-CHITOSAN NANOPARTICLES (CNP) FOR ADVANCED BIO-COMPOSITE

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ABSTRACT
This study delves into the augmentation of polypropylene (PP) with chitosan nanoparticles (CNP) to develop bio-composites tailored for multifaceted applications, particularly in the context of environments. The investigation focuses on characterizing these composites concerning their structural, thermal, degradation, and electrochemical properties. Commercial polypropylene waste obtained from the Federal University of Technology, Akure (FUTA), underwent meticulous processing, converting it into pellets of varying sizes. Chitosan nanoparticles were derived from chitin, procured from a Lagos-based seafood company. These fillers were judiciously chosen for their ability to confer heightened conductivity, cost-effectiveness, biodegradability, and availability. The synthesis involved preparation of nano-chitosan (CNP) through a method wherein chitosan powder underwent dissolution and subsequent reaction with Sodium Tri-Poly-Phosphate (TPP). Composite blends with different weight percentages of PP and CNP were formulated using a solvent casting method. Fourier Transform Infrared Spectroscopy (FTIR) was employed to discern surface functionalities in the PP/CNP bio-composites. The results revealed significant alterations in functional groups upon the introduction of chitosan nanoparticles into the PP matrix, suggesting chemical modifications within the composite structure. Thermogravimetric Analysis (TGA) and Differential Scanning Calorimetry (DSC) elucidated the thermal behavior of the composites, indicating a decrease in thermal stability with increasing CNP content. Water absorption tests displayed variances in absorption rates, with higher CNP content leading to escalated water absorption capabilities due to the hydrophilic nature of chitosan. Soil biodegradability assessments unveiled a direct correlation between chitosan content and degradation rates, evidencing enhanced biodegradability with higher concentrations of chitosan nanoparticles. Electrochemical measurements via Cyclic Voltammetry depicted a marked increase in specific capacitance with 30% CNP inclusion, signifying improved charge storage capabilities in the composite.
Keywords: biocomposite; chitosan; polypropylene; characterization

FLOW AND HEAT TRANSPORT ANALYSIS OF AN UNSTEADY MAGNETO-MICROPOLAR NANOFLUID OVER A CONVECTIVELY HEATED POROUS EXPANDING SURFACE

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ABSTRACT
The nature of heat transfer and flow dynamics in hydromagnetic fluids has broad applications in advanced thermal systems such as polymer extrusion, electromagnetic casting, biofluid transport, and microfluidic devices. Understanding these processes enables precise thermal control, particularly in porous and expandable materials, with implications for cooling technologies, energy systems, and biomedical engineering. This study investigates the unsteady flow of a magneto-micropolar nanofluid over a porous, extending surface under convective boundary conditions. The governing partial differential equations are reduced to ordinary differential equations using appropriate similarity transformations and solved numerically via the Runge-Kutta-Fehlberg method combined with shooting techniques. Graphical and tabular results reveal that increasing the unsteadiness parameter reduces velocity, temperature, and concentration profiles. However, the thermal field intensifies with higher magnetic parameter, thermal radiation, and thermophoresis effects.
Keywords: Magneto-micropolar fluid; Convectively heated sheet; Porous stretching sheet, Thermal radiation; Unsteady fluid flow

MACHINE LEARNING MODELS: THE MATHEMATICAL POWER OF MATRIX DIAGONALIZATION AND QUADRATIC FORMS

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ABSTRACT
Machine learning has become a powerful tool for decision-making and prediction, yet the mathematical foundations that support these models often receive less attention. This paper explores the significant roles of matrix diagonalization and quadratic forms in improving both the performance and clarity of machine learning algorithms. First, we show how diagonalization helps uncover hidden structures in large datasets, particularly through Principal Component Analysis (PCA). Second, we examine how quadratic forms help model and understand the shape of cost functions in optimization tasks. A key contribution of this work is the proposal of a new hybrid technique that combines diagonalization with regularization to speed up convergence in gradient-based learning methods. We support our theoretical insights with real-world examples, such as medical diagnostics and financial predictions. By combining the precision of linear algebra with the adaptability of machine learning, this study enhances both computational efficiency and model interpretability—moving a step closer to truly explainable AI.
Keywords: Matrix Diagonalization; Quadratic Forms; Explainable AI; Principal Component Analysis.

ASSESSMENT OF ACUTE OXİDATİVE RESPONSES İN MEDİTERRANEAN MUSSEL (*Mytilus galloprovincialis*) TO GRAPHENE OXİDE EXPOSURE AND POTENTİAL RESPONSE MODULATİON BY SPİNEL ZİNC FERRİTE ($ZnFe_2O_4$)

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ABSTRACT
The increasing utilisation of microplastics (MPs) and their minimal recycling rates have resulted in their accumulation within aquatic ecosystems, thereby giving rise to a mounting environmental concern. A promising remediation strategy involves the use of magnetic nanoparticles (MNPs) to remove MPs from contaminated habitats. However, the ecological effects of MNP applications remain largely unexplored. This study investigates the potential toxic effects of graphene oxide nanoparticles (GO-NPs) and a magnetic nanoparticle, zinc ferrite ($ZnFe_2O_4$-NPs), on the oxidative stress responses of the bivalve *Mytilus galloprovincialis*. Mussels were collected from a local aquaculture farm and exposed under two experimental setups. In the first, mussels were exposed to GO-NPs at three concentrations (0.1, 1, and 10 mg/L) for 24, 48, and 72 hours. In the second, GO-NPs and $ZnFe_2O_4$-NPs were combined at three concentrations, and mussels were exposed to the products resulting from a 3-hour photocatalytic activation of $ZnFe_2O_4$-NPs, followed by the same time intervals. Oxidative stress biomarkers, including superoxide dismutase (SOD), catalase (CAT), and glutathione-*S*-transferase (GST), were measured spectrophotometrically in gill tissues. Statistically significant increases ($p < 0.05$) in enzyme activities were observed in all exposure groups compared to the control group, with the highest levels detected in co-exposure scenarios involving both GO and $ZnFe_2O_4$ nanoparticles. These findings underscore the necessity of evaluating the combined impacts of engineered nanomaterials utilized in pollution mitigation strategies. The results may contribute to the development of safer and more effective applications of GO-NPs and $ZnFe_2O_4$-NPs in environmental remediation. This study forms part of an MSc thesis conducted at the Graduate School of Çanakkale Onsekiz Mart University.
Keywords: magnetic nanoparticles, bivalve, stress enzymes

DETERJAN KATKI MADDESİ OLARAK BAKTERİ KÖKENLİ YENİ PULLULANAZ TİP I

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ÖZET

Pullulanaz (EC. 3.2.1.41), pullulan ve nişastadaki α-1,6 ve α-1,4 glukozidik bağlarını hedef alan, spesifik hidrolitik aktivite gösteren bir dallanma giderici enzimdir. Özellikle glikoz ve maltoz sakkarifikasyonunda, nişasta dönüştürme süreçlerinde ve deterjan formülasyonlarında endüstride yaygın kullanım potansiyeline sahip önemli bir enzimdir. Endüstriyel uygulamalar için pullulanaz üretirken, kolay üreyebilen, hızlı büyüme ve spesifik etki biçimleri sağlayan mikrobiyal kaynaklar tercih edilmektedir. Özellikle bakteriyel pullulanazlar, pullulanın maltotrioza tam parçalanmasını kolaylaştırmaktadır. Mezofilik ve termofilik bakteriler yeni pullulanaz enzimlerinin üretimi için umut vadeden kaynaklardır.Mevcut çalışma, deterjan formülasyonlarına katkı maddesi olarak eklenebilir özellikte bir bakteriyel pullulanaz üretmeyi ve karakterize etmeyi amaçlamaktadır. Enzim doğal bakteriyel bir suş olan *Bacillus* sp.'den izole edilmiştir. İzole edilen enzim optimum aktivitesini 40°C'de ve pH 7.0'de sergilemiştir. Ayrıca, 1 saat boyunca pH 5.0-11.0 and 25-65°C aralıklarında işlevselliğini ve yapısal bütünlüğünü koruyarak önemli derecede bir stabilite göstermiştir. Enzim, metal iyonlarına, inhibitörlere, anyonik ve non-iyonik surfaktanlara, organik çözücülere ve NaCl'nin farklı konsantrasyonlarına maruz bırakıldığında elde edilen sonuçlara göre, metaloenzim karakterinde, Ca^{2+} bağımlı olmayan, deterjan türevlerine dirençli ve orta derecede halofilik karakterde bir enzim olduğu belirlenmiştir. İnce tabaka kromatografisi analizinde, bu pullulanazın pullulanı ve nişastayı maltotrioza dönüştürdüğü tespit edilmiştir. Buna göre, enzimin α-1,6 glukozidik bağları kıran bir "pullulanaz tip I" olduğu kanısına varılmıştır. Ticari bir sıvı çamaşır deterjanıyla %90 oranında uyumluluk gösteren pullulanaz enzimimizin, gerçekleştirilen yıkama performans analizinde, çikolata ve kayısı püresi gibi nişasta temelli lekelerin gideriminde etkili olduğu gözlemlenmiştir. Deterjan ile pullulanazın birlikte kullanılmasıyla yapılan yıkama sonuçlarına göre, lekelerin neredeyse tamamen giderilmesi, enzimin çamaşır deterjanı endüstrisinde katkı maddesi olarak kullanılma bakımından etkili bir aday olduğunu göstermektedir.

Anahtar Kelimeler: Pullulanaz Tip I, Bacillus, Deterjan Katkı Maddesi, İnce Tabaka Kromatografisi

NOVEL PULLULANASE TYPE I OF BACTERIAL ORIGIN AS DETERGENT ADDITIVE

ABSTRACT

Pullulanase (EC. 3.2.1.41), a debranching enzyme, targets α-1.6 and α-1.4 glucosidic bonds in pullulan and starch, exhibiting specific hydrolytic activity. It is a crucial enzyme with the potential for widespread use in glucose and maltose saccharification, starch conversion processes, and detergent formulations. When producing pullulanase for industrial applications, microbial sources that allow for easy production, rapid growth, and specific modes of action are preferred. In particular, bacterial pullulanases facilitate the complete breakdown of pullulan to maltotriose. Mesophilic and thermophilic bacteria are promising sources for producing new pullulanases. The present study aims to produce and characterize a bacterial pullulanase that can be added to detergent formulations as an additive. The enzyme was isolated from a natural bacterial strain, *Bacillus* sp. The isolated enzyme exhibited its optimum activity at 40°C and pH 7.0. In addition, it showed significant stability by maintaining its functionality and structural integrity at pH 5.0-11.0 and 25-65°C for 1 hour. According to the results obtained when the enzyme was exposed to metal ions, inhibitors, anionic and nonionic surfactants, organic solvents, and various concentrations of NaCl, it is a metalloenzyme, Ca^{2+} independent, resistant to detergent derivatives, and moderately halophilic. In thin-layer chromatography analysis, the pullulanase was found to convert pullulan and starch to maltotriose. Accordingly, it was concluded that the enzyme is a "pullulanase type I" that attacks α-1,6 glucosidic bonds. This pullulanase, 90% compatible with a commercial liquid laundry detergent, effectively removed starch-based stains such as chocolate and apricot puree in wash performance analysis. According to the washing results performed by using the detergent and the pullulanase together, the stains are almost completely removed compared to the washing results performed with detergent alone, indicating that the enzyme is an effective candidate for use as an additive in the laundry detergent industry.

Keywords: Pullulanase Type I, Bacillus, Detergent Additive, Thin Layer Chromatography

MODERN METHOD OF DIFFERENTIAL DIAGNOSIS OF BIOLOGICAL TISSUES

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ABSTRACT

Histological examination of tissue samples obtained during biopsy is usually sufficient to establish the presence or absence of tumor cell complexes and ulcerative changes. Since the zone of spread and invasion of tumor cells and ulcerative lesions can be invisible, the doctor usually relies on his own experience and intuition. Despite the fact that this method is the most reliable and widespread throughout the world, it has a long execution time - up to 6 days, so an alternative or additional method has been developed and proposed, which allows you to determine and differentiate the nature of the lesion much faster, since the duration of the study is only 60 seconds. This method is based on the difference in the concentration of intracellular trace elements in tumor, inflammatory and normal tissues of biological tissues. The results. The authors use the well-known phenomenon of the photo effect. Irradiation of a tissue sample with a mini-γ-quantum causes the cells to lose their negative charge, thus creating a photoelectric effect (Stoletov effect), which will be strictly individual for tumor, inflammatory and normal tissues. To differentiate various pathological formations, the authors measure the intensity of absorption of γ-quanta by cells, as well as the characteristic emission of microelements present in the tissue. Thus, the key point of the presented method is to distinguish the concentration of trace elements in malignant, non-malignant, inflammatory and normal tissues. This circumstance can be explained by the complex and related function of the sodium pump in carcinogenesis. We recommend using the express method of mini-γ-quantum research when taking biopsy material for the differentiation of pathologically changed tissues.

Key words: mini-γ-quantum, differentiation, tissues

TOWARD SUSTAINABLE CRACK REPAIR: ELASTOPLASTIC STUDY OF HYBRID TECHNIQUES FOR ALUMINUM STRUCTURES

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ABSTRACT
This study investigates the mechanical performance of different repair techniques for cracked aluminum structures, aiming at sustainable and efficient crack mitigation. The repair strategies analyzed include composite bonded patches, drilled hole repairs, and their combination, referred to as hybrid repair. Tensile testing and numerical simulations are conducted to evaluate the elastoplastic response of these methods. The finite element method (FEM), implemented using the ABAQUS software, is employed to model the mechanical behavior under Mode I loading. The Notch Stress Intensity Factor (NSIF) is used in conjunction with the volumetric method to assess the stress concentration around the crack tip. Critical parameters such as plastic zone size, normal stress (σ_{yy}), peel stress (σ_{zz}), and Crack Opening Displacement (COD) are used to characterize and compare the repair strategies. Results show that while bonded composite patches significantly enhance the strength of the cracked plate, the inclusion of a drilled hole contributes to additional energy absorption and reduces the maximum normal stress by approximately 50%. The hybrid repair technique demonstrates superior mechanical performance, offering a more robust and durable solution by improving crack resistance and increasing structural lifespan. These results demonstrate the effectiveness of hybrid repair strategies in various engineering sectors such as aerospace, mechanical, and naval engineering, where structural integrity and sustainable solutions are vital.
Keywords: Hybrid, volumetric method, Composite, NSIF, Plastic zone, Drilled.

FINITE ELEMENT ANALYSIS OF STRESS DISTRIBUTION IN BONE DURING INSERTION OF DIFFERENT DENTAL IMPLANT THREAD DESIGNS

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ABSTRACT
The design of an implant's thread plays a crucial role in the osseointegration process, particularly in low-density bone. It is suggested that thread designs which maximize the contact surface area may enhance mechanical anchorage and stability within cancellous bone. The primary stability of a dental implant is primarily determined by the mechanical interlocking between the implant and the surrounding bone at the time of insertion. Therefore, the contact area at the implant-bone interface and the resulting stress distribution on marginal bone are key concerns in implant design. To evaluate the influence of thread design on stress distribution, three-dimensional finite element models of dental prostheses were developed. These models compared four different thread geometries under impact from two types of projectiles. The simulation results revealed that stress concentrations were highest in the bone at the point of contact with the impactor. Among the tested designs, the triangular thread geometry produced the highest stress concentrations. Moreover, conical projectiles generated greater stress levels than spherical ones. These findings indicate that the highest stresses occur initially in the cancellous bone, with potential to extend to the cortical bone. This stress distribution could compromise bone integrity and lead to early implant loosening.
Keywords: Finite element method; Stress distribution; Dental implant; Thread.

VOLUME AND SURFACE ARE CALCULATIONS FOR 3D-PRINTED STRUCTURES

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ABSTRACT
The evolution of 3D printing has transformed industries ranging from healthcare to aerospace, enabling rapid prototyping and complex geometries with unprecedented precision. However, the efficiency of 3D-printed structures hinges on accurate volume and surface area calculations, which directly impact material consumption, structural integrity, and production costs.This study explores the mathematical foundations behind volume and surface area estimations, integrating multiple integral techniques and computational geometry to optimize designs. By leveraging parametric modeling, we demonstrate how adjusting infill density and surface topology can reduce material waste by up to 30%, while maintaining mechanical strength. Additionally, we investigate the role of surface roughness in influencing heat dissipation and aerodynamics, crucial for applications in biomedical implants and aerospace components.Through case studies on biodegradable prosthetics and lightweight lattice structures, we highlight how precise calculations enhance efficiency, sustainability, and performance in additive manufacturing. This research underscores the importance of mathematical optimization in next-generation 3D printing, paving the way for smarter, more resource-efficient production methodologies.

Keywords : Parametric Optimization, Sustainable Manufacturing, Computational Geometry, Additive Efficiency

"JACOBIAN IN ROBOTICS: MOTION PLANNING AND CONTROL"

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ABSTRCT
In this paper, we mainly solve the adaptive control problem of robot manipulators with uncertain kinematics, dynamics, and actuators parameters, which has been a long-standing, yet unsolved problem in the robotics field, because of the technical difficulties in handling highly coupled effect between control torque and the mentioned uncertainties. To overcome the difficulties, we propose a new Lyapunov-based adaptive control methodology, which effectively fuses the inverse Jacobian technique and the actuator adaptation law, with which the chattering in tracking errors caused by actuator parameter perturbation is well suppressed. It is demonstrated that the asymptotic convergence of all closed-loop signals is guaranteed. Moreover, the effectiveness of our control scheme is illustrated through simulation studiesThis electronic document is a "live" template and already defines the components of your paper [title, text, heads, etc.
Keywords: Jacobian, Robotics, Motion Planning, Kinematics, Velocity, Singularity, Trajectory Generation

COATING OF THE SURFACE OF POROUS NITI IMPLANT PRODUCED BY SHS METHOD WITH NANOSTRUCTURED HYDROXYAPATITE BASED BIOCERAMIC

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ABSTRACT
Nickel-Titanium alloys are used in biomedical applications due to shape memory properties and similarity to bone tissue in terms of porosity and elasticity modulus. Hydroxyapatite (HA) is a functional material for use as a biomaterial due to its structure similar to the mineral part of the bone and its ability to bond directly with the bone. In this study, a two-stage production method was utilized. In the first stage, NiTi alloy powders were prepared with different additive elements and ratios. Samples were fabricated as 4 groups of 1%-2%-3% Cu, 1%-2%-3% Ag, 1%-2%-3% Nb and undoped Ni-Ti within the atomic 49.8% Ni and 50.2% Ti as the main structure, respectively. The prepared powders were subjected to the SHS (self-propagating high temperature synthesis) method to obtain a porous structure. In the second stage, nanostructured hydroxyapatite (HA) bio films were coated on porous produced samples by sol-gel and hydrothermal methods. SEM/EDS and XRD analyses were used to determine the structural properties. The electrochemical corrosion behaviors of the samples were compared with potentiodynamic scanning (PDS) measurements in simulated body fluids (SBF) at 37 ± 1 °C. The porosity rates of the samples were measured using the Archimedes principle.When we evaluated the study in two stages, in the first stage; it was observed that the porosity in the structure increased with the increasing ratio of Cu from the alloying elements. It was determined that Nb and Ag elements have similar effects on porosity. When we compared the coating methods in the second stage, it was observed that the sol-gel method had better surface adhesion than the hydrothermal method. The degradation in SBF liquid and the HA (hydroxyapatite) structure in SEM images support this conclusion. It is thought that this situation is caused by free HA particles accumulated in the pores.
Keywords: Biomaterial, HA, NiTi, Coating, SHS

FUROPYRIDINE: IT'S SYNTHESIS, CHEMICAL TRANSFORMATIONS AND BIOLOGICAL APPLICATIONS

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ABSTRACT

The combination of heterocycles renders a new possibility to synthesize multicyclic compounds having improved biological activities. Furopyridine is a fused bicyclic heterocyclic ring system formed by the fusion of a furan ring and a pyridine ring. These heterocyclic compounds can be easily synthesized from versatile starting materials including pyridine, furan, benzofuran, and benzopyridine *via* cycloaddition, cyclo-isomerization, multicomponent, cross-coupling, and Dakin-type reactions by utilizing microwave, copper, and palladium based catalysts. Among the chemical transformations of furopyridine derivatives these included acetylation, addition, condensation, Vilsmeier-Haack reaction, and nucleophilic substitution reactions. Furopyridine has attracted remarkable attention from researchers due to its wide range of pharmacological and biological applications as antibiotic, antiviral, antifungal, anticancer, inhibitors of nicotinic acetylcholine receptors, CLKs, e1F4A, DYRKIA, α-glucosidase and β-glucosidase.

ROLE OF THE SUPPORT PATCH IN MODIFYING STRESS DISTRIBUTION

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ABSTRACT
During a tensile test of a single-cover assembly, it is always noticed that there is a so-called secondary bending of the adhesives which has a negative effect on the strength of the assembly with a remarkable increase in the peel stress. The aim of this work is to analyze numerically by the finite element method the effect of the addition of a patch made of aluminum material on the stress distribution in the adhesive joint. The purpose of adding this patch is to reduce the peel stress which causes deformation and rupture of the joint.
Keywords: Adhesive bonding, Single lap joints, Patch support, Stresses distribution.

EFFECT OF DIFFERENT PARAMETERS ON STRESS LEVELS IN BONE CEMENT USED IN TOTAL HIP ARTHROPLASTY

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ABSTRACT
The objective of this study is to examine the mechanical behavior of a surgical cement used for the fixation of a dual mobility cup to the acetabular bone. Three-dimensional numerical analysis, based on the finite element method, focuses on determining the intensity and distribution of the von Mises equivalent stress generated in the orthopedic cement and the components of the dual-mobility total hip prosthesis under static loads. The study highlights the localization of stress concentration areas, on one hand, at the contact regions between the components, and on the other hand, in the cement surrounding the cup. It is well known that the success of a dual-mobility heavily depends on the initial stability of the cup, which is mechanically linked to the optimal distribution of mechanical stresses at the bone/cup interface. Therefore, finding reasonable solutions to reduce and redistribute these stresses has become a crucial research area. Four factors were studied: the outer diameter of the insert, the Young's modulus of the cup, and the friction coefficients at the femoral head-insert and insert-cup contact surfaces. The results indicate that the Young's modulus of the cup and the insert diameter significantly influence the optimal equivalent stress value in the orthopedic cement. An analytical model was developed as a predictive tool to optimize cement stress.
Keywords: Dual mobility Cup- Finite elements- Stress of bone cement.

USE OF MULTIPLE INTEGRALS IN ASTROPHYSICS AND CELESTIAL MECHANICS

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ABSTRACT
Multiple integrals play a crucial role in astrophysics and celestial mechanics by providing mathematical tools to analyze the behavior and interactions of celestial bodies. These integrals enable precise calculations of mass distributions, gravitational potentials, and orbital dynamics, allowing for a deeper understanding of large-scale cosmic phenomena. In celestial mechanics, double and triple integrals are essential for computing planetary motion, energy variations in orbital systems, and perturbation effects in multi-body interactions. Additionally, integral techniques are used to model density distributions of stars within galaxies and determine center-of-mass coordinates in complex astronomical systems. By leveraging multiple integrals, researchers can refine simulations, improve predictive models, and enhance computational methods for astrophysical studies. This paper highlights key applications of multiple integrals in celestial mechanics, demonstrating their significance in gravitational modeling, orbital calculations, and the study of cosmic structures. The findings underscore the importance of integral-based approaches in solving complex astrophysical problems, contributing to the advancement of space science and our understanding of the universe.
Keywords:Multiple Integrals, Astrophysics, Celestial Mechanics, Perturbation Effect

IMPROVED SOLAR-POWERED PHOTOCATALYTIC BREAKDOWN OF CIPROFLOXACIN ANTIBIOTIC AND ORANGE G DYE USING NOVEL G-C_3N_4/BIOCL/AG_2MOO_4 NANOCOMPOSITE MATERIALS

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ABSTRACT
This study presents the synthesis and application of a novel ternary nanocomposite photocatalyst, g-C_3N_4/BiOCl/Ag_2MoO_4, for the efficient photocatalytic degradation of Orange G dye (OG) and Ciprofloxacin antibiotic (CIP). Comprehensive characterization using XRD, FTIR, SEM, TEM, EDX, and XPS confirms the successful formation of the nanocomposite with high crystallinity. The photocatalytic performance of the nanocomposite, along with its individual components, was evaluated under solar irradiation[1]. Notably, the ternary nanocomposite demonstrated superior efficiency, achieving a 97% degradation of Orange G and a 90% degradation of Ciprofloxacin. The recyclable nature of the nanocomposite was validated through four consecutive cycles, highlighting sustained photocatalytic efficacy.To elucidate the enhanced performance, a proposed photocatalytic mechanism was investigated using UV-vis diffuse reflectance spectroscopy (DRS) and active species capture experiments. Additionally, density functional theory (DFT) and Monte Carlo simulations were employed to optimize the structures and explore the adsorption mechanisms of the pollutant molecules on the nanocomposite surface[2]. These simulations revealed that Orange G exhibits higher adsorption affinity compared to Ciprofloxacin, attributed to its more favorable adsorption energy. These results underscore the potential of the synthesized heterostructures for sunlight-driven OG and CIP degradation, demonstrating their capability to satisfy the stringent

demands for removing antibiotics and dyes from pharmaceutical and industrial wastewater treatment processes.

Keywords: photocatalysis; degradation; removal; orange G dye; Ciprofloxacin antibiotic, sunlight.

REINFORCED NEURAL NETWORKS FOR LUNG CANCER DETECTION

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ABSTRACT
Lung cancer is one of the deadliest diseases which cause high death rates throughout the world. Lung cancer is an irregular growth of cells that can be characteristically derived from a single irregular cell which may spread to whole part of the lung. CT scan is one of the sensitive methods used in the medical field for treating the patients as compared to MRI and X-rays. Diagnosis of cancer from the computed tomography (CT) images of lung is very challenging for doctors. Computer aided diagnosis (CAD) is another tool for detection that uses computer-generated output as an assisting tool for a clinician to form a diagnosis. The biomedical image processing has better ability to detect lung diseases as it helps in analyzing each image and monitoring the data. MATLAB has been used through every procedure made in this study. In image processing procedures, pre-processing of an image is a necessary process as there is difficulty in detecting cancer cells in an image due to the presence of noise and low-quality of images. Steps like image enhancement, image segmentation and feature extraction methods can be used to reduce the degree of those problems. Reinforcement machine learning algorithm is introduced to increase the accuracy rate of detecting tumor growth in lungs. In future, the CT images are collected from health-care centers and remote places through Internet of Things (IoT)-enabled platform and the image is stored in the cloud servers and obtained for processing at any time. The main purpose of this paper is to assist the doctors to detect and classify lung cancer by using CT images based on reinforcement learning algorithm through IoT platform.

Keywords: Computed Tomography (CT), Internet of Things (IoT), Computer aided diagnosis (CAD), Pre-processing, Image Segmentation, Reinforcement Learning Neural Networks

IMPACT OF BIG DATA ANALYTICS ON THE TELECOMMUNICATION INDUSTRY

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ABSTRACT
This study investigates the impact of big data analytics (BDA) on the telecommunications industry, focusing on its role in enhancing decision-making, customer experience, and operational efficiency. The research employs a survey research design, collecting data from a sample of telecommunications professionals through structured questionnaires, and utilizes descriptive statistics and non-parametric tests for analysis. The findings reveal that BDA significantly improves the ability of telecom companies to analyze customer behavior, optimize service delivery, and enhance overall operational performance, while also identifying challenges such as infrastructural limitations, high operational costs, and regulatory hurdles. In conclusion, the study emphasizes the transformative potential of BDA in the telecommunications sector and recommends that companies invest in infrastructure, enhance employee training, foster collaborations with technology partners, engage with regulatory bodies, and commit to continuous research and development to fully leverage big data's capabilities and maintain a competitive edge in the evolving digital landscape.

IoT FOR SMART CITY MANAGEMENT SYSTEM SERVICES IN NETWORK ENABLED APPLICATIONS

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ABSTRACT

Food wastage is becoming a critical problem around the world. The exponential growth in food waste is becoming a serious threat to our society. There is an urgent need to take appropriate measures to reduce food waste burden by adopting standard management practices. The purpose of this project is to introduce a smart food waste management system that is able to handle the process efficiently. We propose a cloud-based smart waste management mechanism in which the waste bins are equipped with load cell and sensors, capable of notifying the food waste generated by every individual to the cloud and they have to pay as much they throw. A notification is sent to the individual mobile phone via a SMS about the weight of the food wasted. This paper provides a steganalysis method to encrypt and decrypt secret information inside image by using steganography techniques like spatial and transform domain. Steganalysis is used to detect messages encrypted using secret key from stego images produced and it can lead to the prevention of security incidents. A secret key is generated for the encryption file which is embedded into the image and the QR-code is generated for the image. The generated QR- Code is used to decrypt the encryption file and image. This paper uses a machine learning (ML) approach in order to distinguish the clean and stego-bearing files for reducing the image size before encryption which will working both content and compression-based image formats. In agricultural science, the quality identification of fruits and vegetables were categorized with differentiating colour, shape, dimension and texture. The proposed technique will enable to develop a smart phone App which uses intelligent image processing algorithms to scan the attributes of the fruits exhibited in a supermarket and assess its nutritional values like total carbohydrates including sugars like glucose, fructose, sucrose, potassium, magnesium and vitamins like vitamin A and vitamin C, antioxidants along with microbial contamination. This instant information received by the customers, once they capture the images of the fruits using the smart phone will kindle their interest to purchase the fruits based on their requirement. Another added feature of this smart phone App is that, it will enable the customers to identify the microbial contamination in fruits and vegetables. Nowadays, mobile phones have become a part and parcel of our life style, that even a common man possesses one

such device. So, this smart phone App once developed will be freely downloaded and installed using the Google play store. The customers, who are the end users, when purchasing the fruits, need to have some related information about the fruits and vegetables which will motivate them to purchase it. This simple technology which is user friendly will facilitate the measurements related to the nutritional value which includes parameters like sugar content, carbohydrates, potassium and vitamins by embedding an intelligent image processing algorithm which will process the photos of the various fruits captured by the camera in the smart phone. This advanced technology of using smart phone App, extracts the color, shape, average intensity and Sum of Absolute Difference (SAD) for various fruits like Mango, banana, orange, papaya and tomato to classify them into three categories like High or Good Quality (HQ or GQ), Medium or Average Quality (MQ or AQ) and Low or Poor Quality (LQ or PQ) with specific and accurate measurements of the total carbohydrates including sugars like glucose, fructose, sucrose, potassium, magnesium, antioxidants and vitamins like vitamin A and vitamin C, displayed on mobile phone screen, instantly. On the other dimension, this novel technology will place an end to the challenge involved, in sorting the fruits and vegetables that can be cultivated using artificial fertilizers which are harmful for consumption. Excessive usage of fertilizers not only decreases the nutritional content but also reduces the taste and flavor of the fruits. The study analyses a method for ternary classification which learns and classifies cover, WOW stego, and UNIWARD stego images using a single CNN-based classifier. Manual extraction of sophisticated features and Ensemble Classifiers or Support Vector Machines are used for digital image processing. An indirect approach is adopted to hide two bits of the secret message into some DCT coefficients that has been selected. The CAPTCHA codes are embedded ASCII into cover image with an encrypted to form a stego image. The steganographic process contains the secret information, the carrier file and steganographic algorithm. Each carrier has its own characteristics which affects the steganographic algorithm. The data to be steganographed is encrypted using AES algorithm to enhance the security. A secret message is hidden inside an image, the image's Encryption and Decryption is performed using AES (Advance Encryption Standard) algorithm and LSB algorithm. The compression and decompression of that image is performed using Huffman Coding. When data is incorporated to the original file there will be changes done to the integrity of the file that is not visible on outer look of the file. The data added is hidden in the file. Therefore there is possibility that the metadata of the file changes. In the LSB approach, the Least Significant Bits (LSB) are replaced on the cover image with the bits of the messages to be hidden.Both the serial and parallel versions are proposed. An analysis of the performances is made using images ranging from 1:9 to 131 megapixels.

Keywords: IoT; cloud- based management; Mobile phone App, Artificial Neural Networks, Back Propagation Algorithm, Genetic Algorithm

SUSTAINABLE ALTERNATIVE FOR TEXTILE COLORATION USING PHENOLIC CONTENTS FROM DIFFERENTS COMBINATION OF EUCALYPTUS CAMLDULENSIS AND CINNAMOMUM VERUM

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ABSTRACT
A dye is nothing but a colored substance that has an affinity to the substrate to which it is being applied.Colour is one of the elements of nature that makes human life more aesthetic and fascinating. There are currently many differents dye extraction processes, including Solvent , aqueous, enzymatic extraction, etc. Dye could be natural dye derive from plants and animals and Artificial dye from chemical industry. Environment pollution is emerging as an alarming issue all over the world.The textile industry regards as the most polluting, as water pollution caused by effluents. These effluents contain toxic chemicals like carcinogenic amines and mutagens in Azo dyes, heavy metals, several natural products have been reported to possess dyeing abilities; Synthetic dyes are allergic, carcinogenetic, non biodegradable and difficult to prepare and cannot be dispose off easily. Though phenolic compound has been showing Natural dyes are Nontoxic, Biodegradable, nonallergic, non carcinogenetic easy to prepare and can be dispose off easily. Eucalyptus camldulensis (E) was blended with Cinnamomum verum (C) in different ratio to attained three differents hybrid forms. The extracts blended in the following ratios and labelled accordingly; 1:1 labelled CS_1, 4:1 labelled CS_2 and 1:4 labelled CS_3. A phytochemical screening revealed presence of compounds responsible for dyeing properties in the crude extracts of Eucalyptus camldulensis,Cinnamomum verum and blended portions.phytochemical analysis shows flavonoids, quinones, tannins, carotenoids, alkaloids, coumarins. This research reveal phenolic contents in both Eucalyptus camldulensis and Cinnamomum verum.

Keywords: Natural Dyes, Classification, Extraction-Method, Application, Eco-Friendly.

ECO-FRIENDLY SYNTHESIS AND BIOMEDICAL EVALUATION OF ZINC OXIDE NANOPARTICLES DERIVED FROM *MORINGA OLEIFERA* LEAF EXTRACT

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ABSTRACT
The present work highlights an eco-friendly method for the synthesis of zinc oxide nanoparticles (ZnO NPs) using *Moringa oleifera* leaf extract as a natural reducing and stabilizing agent. The synthesized nanoparticles were thoroughly characterized using UV-Visible spectroscopy, FTIR, XRD, SEM, and EDS techniques to determine their physicochemical properties.The UV-Vis spectrum exhibited a prominent absorption peak at 376 nm, confirming nanoparticle formation. FTIR analysis detected functional groups associated with Zn–O bonds, phenolic hydroxyls, carboxylic acids, and alcohols. X-ray diffraction confirmed the crystalline nature of the ZnO nanoparticles, while elemental analysis revealed major components such as zinc (65.18%), oxygen (19.21%), and calcium (15.61%). SEM imaging displayed aggregated, irregular particle structures, and EDS analysis confirmed the elemental composition, with zinc and oxygen representing 38.54% and 46.41%, respectively.Biological activity tests demonstrated limited antioxidant and anti-inflammatory properties, while the nanoparticles exhibited strong anti-hemolytic activity, reaching nearly 90% protection. Antimicrobial assays showed effective inhibition against bacterial strains including *Staphylococcus saprophyticus*, *Staphylococcus aureus*, and *Escherichia coli*. Furthermore, ZnO nanoparticles were found to prolong the activated partial thromboplastin time (aPTT) beyond 100 seconds, indicating potential anticoagulant effects.Overall, the biosynthesized ZnO nanoparticles exhibit promising biomedical properties, supporting their application in future therapeutic and antimicrobial strategies.
Keywords: Green synthesis, *Moringa oleifera*, Zinc oxide nanoparticles, Antioxidant, Antimicrobial, Anti-hemolytic activity

PREPARATION AND BIOLOGICAL SCREENING OF HYDRAZONES USING ISOLATED CHOLIC ACID

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ABSTRACT
Natural product modification is one of the key areas of synthetic organic chemistry for the accomplishment of valuable chemical building blocks that have prized medicinal significance. Hydrazones possess an azomethine (-NHN=CH-) group and are considered derivatives of aldehydes and ketones in which the oxygen atom has been replaced by the (R-NHN=C) functional group. These are widely studied molecules owing to their ease of preparation and diverse medicine, agriculture and pharmacology potential. Herein, cholic acid based hydrazones were synthesized and characterized using spectroscopic techniques. The newly synthesized cholic acid based hydrazones were screened for their anticancer and antioxidant potentioal. Antioxidants showed their activity by inhibiting the oxidative chain reactions that produce reactive oxygen species. The antioxidant activity showed that 4-NBCH exhibited the maximum DPPH inhibitory activity when compared with other synthesized compounds. The compound purified by thin-layer chromatography and column chromatography. Characterized by Ultra-Violet Visible Spectroscopy, Infra-red, Mass Spectrometry and Nuclear Magnetic Resonance Spectroscopy. Finally, the synthesized compound tested for its biological activities like anti-microbial, anti-oxidant and anti-cancer.
Keywords: Cholic acid, Anti-microbial, Anti-oxidant, DFT Study, Spectroscopic Analysis.

SYNTHESIS AND BIOLOGICAL EVALUATION OF AMIDES USING COUMARIN-3-CARBOXYLIC ACID

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ABSTRACT

Primary, secondary, and tertiary amides have been synthesized by one-pot synthesis from coumarin-3-carboxylic acid by using $SOCl_2$ and triethyl amine which have significant importance in the pharmaceutical field in the scenario of having biological activities like antimicrobial and anti-oxidants in the priority list. Reaction results are admirable at low temperature and can be pure by washing or column chromatography/preparative column chromatography. Amides are widespread in biologically active compounds with various applications in biotechnology, agriculture and medicine. Herein, Coumarin 3 Carboxylic acid based amides N-(2-hydroxyethyl)-2-oxo-2H-chromene-3-carboxamide (EACA),N-(4-fluorophenyl)-2-oxo-2H-chromene-3-carboxamide (4FCA), N-(3-ethylphenyl)-2-oxo-2H-chromene-3-carboxamide(3EACA),N-(2-chloro-5-nitrophenyl)-2-oxo-2H-chromene-3-carboxamide (2C5NCA), N-(3-fluorophenyl)-2-oxo-2H-chromene-3-carboxamide and N-(3-chloro-4-fluorophenyl)-2-oxo-2H-chromene-3-carboxamide were synthesized and characterized using spectroscopic techniques. The newly synthesized coumarin 3 carboxylic acid based amides were screened for their antibacterial and antioxidant potential. Antioxidants showed their activity by inhibiting the oxidative chain reactions that produce reactive oxygen species. The antioxidant activity showed that 2C5NCA exhibited the maximum DPPH inhibitory activity when compared with that of EACA, 4FCA, 3EACA, 3FCA, and 3C4FCA. While 3C4FCA showed maximum antibacterial activity(E.coli) as compared to other synthesized amides, while in the scenario of S aureus, 3FCA showed maximum activity as compared to 4FCA, EACA, 3EACA, 3C4FCA, and 2C5NCA.By this method, a series of novel coumarin-3-carboxamides were designed and synthesized to evaluate their biological activities.

Keywords: Coumarin-3-carboxamides, Anti-microbial, Anti-oxidant, DFT Study, Spectroscopic Analysis

PHENYLAZONAPHTHALENE-BASED AZO DYES ARE MODIFIED CHEMICALLY TO ENHANCE THEIR PHOTOVOLTAIC QUALITIES FOR USE IN DSSCS. DFT AND TD-DFT ANALYSIS

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ABSTRACT
Dye-sensitised solar cells (DSSCs) are of significant interest to researchers in the field of solar cell research due to their affordability and enhanced energy efficiency. In this study a theoretical analysis was performed on five phenylazonaphthalene-based azo dyes, utilising quantum methods, including density functional theory (DFT/B3LYP/SDD/6-311+G(d,p)) and its time-dependent derivative (TD-DFT/CAM-B3LYP/SDD/6-31+G(d,p)). The structural, electronic and optical properties of the dyes under study (C_1, C_2, C_3, C_4 and C_5) were examined and discussed, including FMO energy gap (E_g), chemical hardness (η), electronegativity (χ), chemical potential (μ), open circuit voltage (V_{oc}), softness (S), molecular electrostatic potential (MEP), light harvesting efficiency (LHE), injection driving force ΔG_{inject}, NBO analysis and maximum electronic absorption (λ_{max}). The following properties were calculated in order to evaluate their potential applications in dye-sensitised solar cells (DSSCs).
Keywords: Azo-dye; Phenylazonaphthalene**;** DSSCs; optoelectronic properties; DFT and TD-DFT.

IN SILICO STUDY OF NOVEL MOLECULES WITH ANTICONVULSANT POTENTIAL TARGETING THE $GABA_A$ RECEPTOR

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ABSTRACT
Epilepsy is a chronic neurological disorder characterized by excessive neuronal activity. In this context, the $GABA_A$ receptor, the main inhibitory mediator in the central nervous system, represents a key target for the development of new anticonvulsant drugs. In this study, we selected molecular structures inspired by bioactive compounds reported in the literature and evaluated their interaction with the $GABA_A$ receptor through molecular docking. The most promising compounds were further analyzed using molecular dynamics to assess the stability of the formed complexes. ADMET predictions and retrosynthetic analysis were also performed to evaluate their pharmacological profiles. The results highlight several promising candidates for the development of novel antiepileptic therapies.
Keywords: epilepsy, molecular docking, $GABA_A$, ADMET, molecular dynamics.

NICKEL OXIDE NANOPARTICLES GRAFTED ON GRAPHENE OXIDE (NIO/GO) AS PHOTOCATALYST FOR THE DEGRADATION OF CLOTHIANIDIN UNDER SUNLIGHT IRRADIATION

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ABSTRACT

This research study focuses on the synthesis of NiO nanoparticles using green pea peels (*Pisum Sativum*) extract, graphene oxide (GO) by amended Hummer method, and their nanocomposite (NiO/GO) by ultrasonication method for the photocatalytic degradation of clothianidin in water. The nanocomposite was characterized by SEM, FTIR, and XRD to investigate the morphology, functional groups, and crystallinity of the material respectively. The maximum degradation of clothianidin (86%) was achieved at pH 3.0 within 60 minutes under the irradiation of natural sunlight. The degradation efficiency increases with the augmentation of the dose of nanocomposite by up to 0.7 g and no prominent change was observed after this threshold value. The degradation efficiency of NiO/GO nanocomposite dropped from 93% to 66% with increasing in the initial concentration of clothianidin. Similarly, a reductio in the degradation efficiency was observed with augmentation in temperature and agitation speed. In general, this research work publicized that the fabrication of NiO/GO nanocomposite is surely an encouraging candidate for the treatment of wastewater at industrial levels under the irradiation of natural sunlight.

DEVELOPMENT OF TECHNOLOGY FOR IN VITRO PROPAGATION AND STORAGE OF ATROPA BELLADONNA L.

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ABSTRACT
Bulgaria is relatively small in area, it has a rich biological diversity due to the highly varied climatic, geological, topographical and hydrological conditions. The Bulgarian flora is a source of plant species rich in a large set of chemical components – specific substances or groups of compounds that are in limited populations. The species Atropa belladonna L. is distributed in forested areas throughout the country. Due to the presence of atropine and scopolamine, the herb is highly poisonous. The application of modern reproductive technologies provides a chance to evaluate, characterize and preserve the species Atropa belladonna, study them under controlled conditions and return them to their natural habitats for the purpose of their preservation. The effect of BAP on the regeneration response of explants was studied using concentrations of 0.5; 0.7; and 1.0 mg/l. Murashige and Skoog (1969) medium. The best development of the species is reported on the 20th and 30th day on Murashige and Skoog (1962) medium containing 0.5 mg/l BAP. The multiplication factor for this variant is 1:5, and for the control variant 1:4. With increasing observation period, the leaf number indicators change significantly. The low concentration of the studied cytokinin does not allow A. belladonna to realize the maximum of its development potential in controlled conditions.
Keyword: plant genetic resources, in vitro, Atropa belladonna L., BAP, micropropagation

DESIGN AND OPTIMIZATION OF POLYANILINE-COPPER OXIDE NANOCOMPOSITES FOR SUSTAINABLE WASTEWATER TREATMENT

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ABSTRACT
In this study, organometallic nanocomposites based on polyaniline (PANI) and copper oxide (CuO), prepared through an in-situ polymerization process. Aniline was used as the monomer, while copper chloride served as both the oxidizing agent and the precursor for CuO formation, with sodium hydroxide aiding in nanoparticle generation. The resulting PANI@CuO nanocomposites were thoroughly characterized using techniques such as FTIR, XRD, UV-Vis spectroscopy, SEM, and analysis of the point of zero charge (pH_{pzc}). The nanocomposites were evaluated for their catalytic and photocatalytic performance in degrading organic dyes—namely Methylene Blue (MB), Congo Red (CR), and Malachite Green (MG)—under various experimental conditions. Optimization through the Box-Behnken Design (BBD) method identified optimal conditions for MB degradation, achieving up to 95% efficiency under ultrasonic irradiation and 74% without it. Additionally, high removal efficiencies were recorded for MB (85%), CR (92%), and MG (97%) under photocatalytic conditions. Computational studies revealed a synergistic interaction between the dye molecules and the PANI@CuO framework, enhancing charge transfer and overall catalytic activity. The nanocomposites also showed excellent stability and reusability across multiple cycles, underscoring their potential for eco-friendly wastewater treatment solutions.
Keywords: Nanocomposites, in-situ polymerization, catalytic activity. Dyes degradation

NUMERICAL STUDY OF ELLIPTICAL CRACKS IN PIPELINE WITH A THICKNESS TRANSITION

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ABSTRACT
Pipelines designed to transport oil and gas are commonly buried underground and constructed from steel with high mechanical strength, featuring both internal and external protective coatings. Despite these measures, such pipelines remain vulnerable to structural defects like material loss or crack formation. To mitigate catastrophic failures, continuous monitoring and analysis are essential throughout their operational lifespan. This study focuses on semi-elliptical cracks in pipelines with thickness transitions, where two butt-welded pipes of differing thicknesses (t_1 and t_D) are joined via a linearly tapered transition zone. Using three-dimensional finite element method (FEM) simulations in ABAQUS 6.14, this research investigates how the crack's geometry, location, and applied loading conditions influence the mode I stress intensity factor (SIF). The findings aim to enhance predictive maintenance strategies and structural integrity assessments for these critical infrastructure components. It is noticed that is a strong domination of the simple traction even in combination with the pressure whereas the SIF of the crack is very weak in pressure this indicates that the opening of the lips of the crack is very favoured by the traction.
Keywords: Thickness transition, cracks, stress intensity factor (SIF), API X55, Scratch

PHYTOCHEMICAL SCREENING AND INVESTIGATION OF ANTIOXIDANT, ANTIBACTERIAL ACTIVITY OF CRUDE METHANOLIC EXTRACTS OF *LITCHI SINENSIS* (DESHI) FRUIT PERICARP

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ABSTRACT

Context: *Litchi sinensis* is a medium-sized evergreen tree from the Sapindaceae family, native to Southeast Asia and China. Its fruit pericarp is rich in phytochemicals such as phenolics and flavonoids, which possess antioxidant and antimicrobial properties, potentially helping to reduce oxidative stress and combat diabetes, cancer, and infections. Objective: The current study aimed to identify and quantify the qualitative and quantitative phytochemical analysis to determine the biological activities and evaluate the antibacterial effects of methanolic extracts from *L. sinenesis* fruit pericarp. Materials and methods: Litchi pericarp was extracted with 99.99% methanol using a rotary evaporator. Antioxidant activities were evaluated via the DPPH method, Folin-Ciocalteu method, and aluminum chloride assay. Antibacterial activity was tested using the agar well diffusion method, and preliminary phytochemical analysis identified various compounds. Results: The methanolic crude extract showed strong DPPH radical scavenging activity with an IC_{50} value of 3.07 ± 0.015 µg/mL, lower than ascorbic acid's IC_{50} value of 5.17 ± 0.05 µg/mL and the total phenolic , flavonoid, and tannin content were 258 ± 0.027 mg GAE/g, 170.8 ± 0.046 mg QE/g & 169.33 ± 0.057 mg GAE/g . Antibacterial testing at doses from 500 µg to 1500 µg per disc revealed modest activity against Gram-positive bacteria (*S. aureus ,B. subtilis, B. licheniformis and B. cerus*) and significant activity against Gram-negative bacteria (*P. auruginosa* and *E. coli*) compared to the standard Kanamycin (30 µg/disc) which shows that the plant extract has potential antioxidant and antibacterial properties for pharmaceutical use. Conclusion: The findings suggest a need for further research to identify new anti-carcinogenic and antibacterial drugs. Additional studies are required to understand the underlying mechanisms and isolate the active compounds responsible for these effects.

Keywords: Litchi sinenesis, Phytochemical, Phenolic, Flavonoid, DPPH, Anti-carcinogenic.

AI-POWERED PRECISION IRRIGATION FOR SUSTAINABLE AGRICULTURE: ENHANCING WATER USE EFFICIENCY THROUGH INTELLIGENT SYSTEMS

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ABSTRACT
Efficient irrigation in salt-affected and arid lands is crucial for maintaining agricultural productivity amid growing water scarcity and land degradation. This study presents an integrated framework for precision irrigation using Artificial Intelligence (AI), specifically tailored to the dynamic conditions of saline soils and arid climates. By fusing real-time data from soil moisture, salinity, and climatic sensors with advanced machine learning algorithms, the system provides optimized irrigation recommendations aimed at minimizing water loss, mitigating salt buildup, and enhancing crop yield. The proposed AI model is supported by IoT-enabled infrastructure, edge computing, and automated irrigation hardware. Experimental results demonstrate improvements in water use efficiency and reductions in soil salinity compared to traditional irrigation practices. This work contributes to the development of resilient and intelligent water management strategies for sustainable agriculture in vulnerable agroecosystems.
Keywords: Artificial Intelligence, Smart Irrigation, Soil Salinity, Arid Land Agriculture, Precision Water Management, IoT in Agriculture

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ABSTRACT
The employment of integral calculus varies in numerous directions, rendering it vital for modeling, evaluating, and resolving practical world issues. In physics, integrals are utilized to measure things like work done or distributed electric charges to mention but a few. Example in this case is that when a variable force is acting on an object its work can be found by integrating the force over that particular distance. On the other hand engineering applies calculus mainly during design stages by studying stress-strain distributions optimizing shapes as well predicting how they will behave in future.It is through integrals that economists can find out consumers' surplus producers' surplus total revenue as well as expenses facilitating market flow. Also in calculus populations grow while drugs diffuse through bloodstream hence this is helpful too even though it is used more often within biology than medicine itself (Perrin, 1981). Similarly environmentalists utilize integrals to evaluate pollution levels or quantity of resources found in nature.Furthermore computer graphics utilize calculus as a means of enhancing curves surfaces and animations. In statistics and probability theory likewise, it finds application in calculating probabilities for the continuous random variables

and expected values. Thus, from improving business operations to supporting scientific studies, applications of integral calculus have led to innovation across different sectors which shows its importance in understanding and controlling the environment.

Keyword: Integral Calculus , Electrical Charge , Stress-Strain Distribution

ISOLATION AND CHARACTERIZATION OF NEWLY IDENTIFIED LACTIPLANTIBACILLUS PLANTARUM PROBIOTIC STRAINS

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ABSTRACT

Probiotic bacteria have become a subject of increasing interest in the scientific community due to their remarkable potential to promote human health and well-being. Lactic acid bacteria (LAB) and bifidobacteria are the primary microorganisms used as probiotics. Among these, *Lactiplantibacillus plantarum*, a lactic acid bacterium, has gained significant attention due to its multifaceted health benefits ; probiotic potential and its isolation from diverse sources, including dairy products and humans and animal guts.The current study aimed to characterize the probiotic potential of *Lactiplantibacillus plantarum* strains isolated from goat milk, traditional dhan butter, and newborn stools. These LAB species are recognized for their probiotic properties and their essential role in fermentation. Safety assessments confirmed that none of the isolates posed any health risks, as they exhibited no gelatinase, hemolytic activity. 14 LAB strains demonstrated survival rate against low pH, high tolerance to bile salts and broad antibacterial activity against the main tested pathogens. The obtained findings indicated that all the 14 LAB strains exhibited a high affinity towards xylene (more than 64%) and auto-aggregation properties, as well as strong degrees of co-aggregation with *S.aureus* and *E. coli*. The strains have been identified as valuable producers of protease and beta-galactosidase.. The selected strains are safe based on their susceptibility to

antibiotics. In conclusion, The strain Ls7 exhibited multifunctional properties as promising candidate probiotics, suggesting that further in vivo trials should be conducted to assess their suitability as probiotics and their potential health-promoting properties in nutrition and health, or for the development of innovative functional foods.

Keywords: Lactic acid bacteria, probiotic, fermentation, antibacterial activity

*CORDIA SINESIS*AMELIORATES DIABETES ASSOCIATED DYSLIPIDEMIA IN STZ INDUCED DIABETIC RATS

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ABSTRACT
Diabetes Mellitus refers to a collection of metabolic disorders that result in elevated blood glucose level (hyperglycemia). Dyslipidemia, a metabolic disorder that is frequently linked to diabetes, is typified by a variety of quantitative and qualitative alterations in lipids and lipoproteins. The seeds of *Cordia sinensis* possess strong sticking and emulsifying qualities that make them suitable for use as antioxidant carriers.This study aims to explore the ameliorative effect of *C.sinesis*against diabetes-associated dyslipidemia. In this study, a total of thirty-six wistar rats were allocated into 6 experimental groups. Group 1served as the normal control (normal feed diet). Group 2 was diabetic control group (diabetes was induced with 30% high-fat diet (HFD) using a low dose of streptozotocin (55mg/kg body weight) intraperitoneally). Group 3, the standard group,received Metformin (250 mg/kg). Groups 4, 5,and 6 were test groups, treated with ethyl acetate extract of *C.sinensis* at doses of 150 mg/kg, 250 mg/kg, and 350 mg/kg, respectively, for 28 days.At the end of the study,serum and tissue samples were collected andbiochemical markers (serum glucose, insulin), insulin resistance markers, and lipid profiles were measured. ANOVA was used to evaluate the data, and Tukey's test was used to assess significance among groups. Results demonstrated that C.*sinesis* significantly reduced the serum glucose levels and significantly improved the serum insulin levels. Insulin resistance was also reduced in *C.sinesis* treated rats. *C.sinesis* significantly improved the lipid profile via significant reduction in TC, TG, LDL and VLDL levels and appreciable improvement in HDL levels in treated groups.
Keywords:*C.sinesis;* Diabetes Mellitus; Lipid profile; Insulin resistance; HDL

CLIMATIC INFLUENCES ON SEXUAL AND REPRODUCTIVE HEALTH: ASSESSING THE PATTERNS OF URINARY TRACT INFECTIONS AMONG WOMEN AND ADOLESCENTS IN KAMRANGIRCHAR, DHAKA

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ABSTRACT
Climate variability significantly influences sexual and reproductive health, with urinary tract infections (UTIs) posing a major concern for women and adolescents in environmentally vulnerable regions. This study examines the prevalence and risk factors of UTIs in Kamrangirchar of Dhaka by employing a mixed-methods approach. Quantitative data is collected through structured surveys from 250 participants, focusing on socio-demographic characteristics, hygiene practices, and UTI symptoms. Environmental sampling of water and soil sources is conducted to assess microbial contamination, including Escherichia coli and other UTI-associated pathogens. Additionally, meteorological data (temperature, humidity, and precipitation) from national archives is analyzed to establish correlations between climatic conditions and UTI prevalence. Qualitative insights from focus group discussions and in-depth interviews further explore community perceptions, health-seeking behaviors, and healthcare barriers. Preliminary findings suggest a higher prevalence of UTIs in Kamrangirchar, likely attributed to increased humidity, saline water intrusion, and recurrent flooding, which exacerbate water and soil contamination. A correlation between extreme temperatures and UTI incidence, particularly during the dry season when water scarcity intensifies, is also expected. Structural challenges, including inadequate sanitation infrastructure, limited healthcare access, and socio-economic constraints, are identified as key factors influencing disease burden. The study underscores the critical need for climate-adaptive public health policies, improved sanitation, and targeted interventions to mitigate the impact of climatic variations on UTI prevalence. These findings contribute to a broader understanding of climate-driven health vulnerabilities and inform region-specific strategies to enhance sexual and reproductive health outcomes in Bangladesh.

Keywords:
Climatic Variations, Climatic Influences, UTI, Bangladesh, sexual health

IMPACT OF BIG DATA ANALYTICS ON THE TELECOMMUNICATION INDUSTRY

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ABSTRACT
This study investigates the impact of big data analytics (BDA) on the telecommunications industry, focusing on its role in enhancing decision-making, customer experience, and operational efficiency. The research employs a survey research design, collecting data from a sample of telecommunications professionals through structured questionnaires, and utilizes descriptive statistics and non-parametric tests for analysis. The findings reveal that BDA significantly improves the ability of telecom companies to analyze customer behavior, optimize service delivery, and enhance overall operational performance, while also identifying challenges such as infrastructural limitations, high operational costs, and regulatory hurdles. In conclusion, the study emphasizes the transformative potential of BDA in the telecommunications sector and recommends that companies invest in infrastructure, enhance employee training, foster collaborations with technology partners, engage with regulatory bodies, and commit to continuous research and development to fully leverage big data's capabilities and maintain a competitive edge in the evolving digital landscape.

MICROBIAL QUALITY ASSESSMENT OF TRADITIONAL RICE AND GROUNDNUT PUDDY IN KADUNA METROPOLIS

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ABSTRACT
Rice and groundnut puddy is a traditional non-alcoholic beverage widely consumed across Northern Nigeria. Despite its popularity and nutritional appeal, concerns over its microbiological safety remain, particularly due to unsanitary production environments and absence of regulatory oversight. This study aimed to evaluate the microbiological quality of locally prepared rice and groundnut puddy sold across four major districts in Kaduna Metropolis: Sabon Tasha, Kawo, Tudun Wada, and Hayin Rigasa. Twenty (20) composites samples were collected and analyzed for bacterial and fungal load using standard microbiological methods. Bacterial and fungal isolates were identified through Gram staining, cultural characteristics, and biochemical tests. Statistical analysis (ANOVA) was performed to assess differences in microbial loads across locations, with significance set at $p \leq 0.05$. All samples were contaminated with microorganisms, with significant variation in microbial loads across locations ($p < 0.05$). Tudun Wada samples showed the highest mean bacterial load ($9.34\times10^6 \pm 2.54$ CFU/ml) and fungal load ($4.20\times10^4 \pm 1.30$ CFU/ml), while Sabon Tasha and Hayin Rigasa had the lowest bacterial and fungal loads respectively. The most frequently isolated bacteria were *Staphylococcus aureus* (44%), *Bacillus* spp. (36%), and *Escherichia coli* (20%). Fungal isolates included *Aspergillus* spp. (53.9%), *Fusarium* spp. (23.1%), *Saccharomyces* spp., and *Penicillium* spp. (each 11.5%). These findings reveal a significant public health concern, as many of the identified microorganisms are known foodborne pathogens. The high microbial loads likely result from poor hygiene during production and handling. There is an urgent need for public health intervention, improved hygiene practices, and regulatory policies to ensure the microbial safety of traditionally prepared beverages like rice and groundnut puddy.
Keywords: Microbiological Quality, Traditional Beverages, Rice and Groundnut Puddy, Foodborne Pathogens, Public Health

REINFORCEMENT SHAPES AND DISTRIBUTION INFLUENCE ON FGM RESONANCE

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ABSTRACT
In this paper, we investigate the nonlinear vibration behavior of shallow shells reinforced with carbon nanotubes (CNTs). The reinforcement is modeled as functionally graded (FG) along the radial direction of the shell. The material properties of these functionally graded carbon nanotube-reinforced composites (FG-CNTRCs) are assumed to vary through the shell thickness, estimated via a micromechanical model. Nonlinear partial differential equations are derived using the Von Karman geometric nonlinear theory, assuming the shell follows classical shell theory. The problem is reduced using the Galerkin technique, leading to a system of nonlinear equations with quadratic and cubic terms. These equations are solved using the method of multiple scales (MMS) for simply supported boundary conditions. Our findings indicate that the distribution of carbon nanotubes, mode shapes and the shell's curvature significantly influence the natural frequencies.
Keywords: Galerkin method; Functionally Graded Carbon Nanotube; Fundamental Linear Frequency, resonance.

MOLECULAR DETECTION OF AN EMERGING CLUBROOT PATHOGEN *Plasmodiophora brassicae* FROM MUSTARD PLANT (*Brassica* spp.)

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Abstract
Mustard (Brassica spp.) is one of the most important oilseed crops and the production area is increasing every year, but the total yield is hampered by the causal agent of soil borne protist Plasmodiophora brassicae causing clubroot disease worldwide including Bangladesh. This pathogen was first detected in Bangladesh on December 2011 through symptomatic study, but no further studies were found about this devastating disease. But, this disease incidence was increasing in last few years and reduces the yield as well. In response to address this growing threat, we collected infected root samples from the mustard growing areas. Then, the genomic DNA was extracted from the infected clubroot samples and the Plasmodiophora brassicae specific primers (PB-F/PB-R; 657 bp) was used for detection. The obtained sequences were examined for the identification and confirmation of Plasmodiophora brassicae pathogen through BLAST, phylogenetic tree and multiple Sequence Alignment. We found that our isolate NSTU_Plasmodiophora brassicae was belongs to a reference ribosomal DNA gene sequence of a Plasmodiophora brassicae isolate NGY (GenBank accession number AB526843). The identified pathogen could be a valuable research material for taking any effective control measures to minimize the yield losses. Our future aims will concentrate on the race/s detection of Plasmodiophora brassicae and effective control strategies against this disease.
Keywords: Plasmodiophora brassicae, Clubroot disease, Mustard (Brassica spp.), Molecular detection, Phylogenetic analysis

FLOWING INTO THE FUTURE: INNOVATIONS FOR WATER SECURITY AND SUSTAINABILITY

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ABSTRACT
Water security is indispensable for economic and social progress but is under hazard due to climate change and environmental degradation. Global warming, more frequent heat and drought conditions, and erratic rains exacerbate water scarcity, threatening public health, industry, and agriculture. Water pollution, land degradation due to deforestation, and institutional incapacity contribute pressure to receding water supplies.Water scarcity has various implications, promoting food insecurity, economic uncertainty, and geopolitical tension. Increased demand puts pressure on vulnerable infrastructure, particularly in the urban setting. Urbanization is likely to intensify over-extraction, depletions, and pollution, which prevents the availability of clean water. Weak regulations and mismanagement exacerbate them, causing uneven water allocation and increased rivalry.The call is for rapid response to these issues. The most important steps are legislative change towards sustainable water policy, investment in effective technologies, and enhanced transboundary cooperation. Technologies such as desalination, wastewater reuse, and intelligent irrigation can supplement conservation. International cooperation with policy-relevant evidence can build climate water stress resilience.This research emphasizes the importance of science-based, innovative ways of providing water resources. By combining ecological sustainability with development objectives, communities can improve water crisis resilience and provide long-term supply. An innovative approach with emphasis on stable policies, technology, and international cooperation is the key to sustainable water management and a secure future.
Keywords: Water security, climate change, environmental degradation, extreme weather events

MOLECULAR INVESTIGATION OF SINGLE NUCLEOTIDE POLYMORPHISM IN COMPLEMENT COMPONENT 5 GENE FOR MASTITIS IN NELI RAVI BUFFALO

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ABSTRACT
Pakistan is ranked fourth in milk production worldwide, after India, China, and the United States. The buffalo breeds reside in the Pakistan are Neli Ravi, Murrah, Water Buffaloes, Kundhi, Azi Kheli, Nili and Ravi. Neli Ravi breed is a well-known breed of buffalo and globally recognized because of their discrete characteristics. Buffalo experiences a number of diseases such as mastitis, theileriosis, anaplasmosis, babesiosis, foot and mouth disease, lumpy skin disease and buffalopox. Mastitis, or inflammation of the mammary gland, is one of the most prevalent diseases that is classified by the mammary gland's inflammatory reaction. Clinical and subclinical mastitis not only lowers milk production but also lowers the nutritional content of milk, which leads to significant financial losses. Worldwide, the dairy industry suffers large and regular financial losses as a result of mastitis. This financial stress is brought on by the increased costs of treating mastitis as well as losses from a variety of problems, such as decreased milk production, rejected milk, and culling. *S. aureus* is the most significant pathogens, responsible for clinical and subclinical mastitis in all over the world. The current study was designed to sequence and analysis of the whole coding region of C5 gene in Neli Ravi buffalo, to identify single nucleotide polymorphism and to find out the association analysis of C5 gene as an indicator of mastitis in dairy animals. Sequence analysis of C5 gene aid as a molecular marker for mastitis resistance and subsequently to be used in a selection of buffalo.
Key words: Mastitis, buffalo, Milk, Marker

A NOVEL ELLIPTIC CURVE-DRIVEN PIXEL SCRAMBLING TECHNIQUE FOR STRENGTHENING PTFT BASED IMAGE ENCRYPTION

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ABSTRACT
The Phase Truncated Fourier Transform (PTFT), introduced in 2010, is a widely recognized optical asymmetric technique used in image encryption. However, despite its initial success and intrinsic strength, PTFT approach was later found vulnerable to certain attacks leveraging phase retrieval algorithms, raising security concerns. This paper addresses these concerns by proposing a novel enhancement through elliptic curves. The proposed method employs an elliptic curve with highly sensitive parameters to perform dynamic pixel scrambling, significantly improving security while maintaining computational efficiency. The effectiveness of the proposed cryptosystem is evaluated through simulations on grayscale images using MATLAB 2023b. Security assessments include statistical analyses such as histogram uniformity tests, mesh plot visualizations, entropy computations, and correlation distribution studies to test resistance against statistical attacks. Additionally, performance metrics like peak signal-to-noise ratio, mean squared error, and correlation coefficient are computed to validate encryption and decryption scheme. The scheme demonstrates resilience against occlusion and noise-based attacks, ensuring reliable data recovery even under partial data loss or signal distortion. Experimental results confirm that the elliptic curve-enhanced PTFT cryptosystem not only mitigates the weaknesses of traditional PTFT but also provides superior resistance against specialized cryptographic attacks. This fusion of optical encryption and algebraic Elliptic Curve Cryptography principles offers a highly robust and secure framework for digital image protection in sensitive applications such as medical imaging, military communications, and multimedia data storage. The proposed approach sets a new benchmark for secure asymmetric cryptosystems in optical encryption domains.
Keywords: Phase truncated Fourier transform, pixel scrambling, elliptic curve, asymmetric image encryption, optical cryptosystem, statistical attack resistance.

LAPLACE TRANSFORMS

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ABSTRACT
The Laplace transform is a powerful mathematical tool widely used in engineering, physics, and applied mathematics to simplify the analysis of complex systems. Its primary application lies in converting differential equations into algebraic equations, making it easier to solve problems involving dynamic systems. In electrical engineering, the Laplace transform is essential for analyzing linear time-invariant systems, particularly in the design and analysis of circuits and control systems. It helps in determining system behavior, stability, and response without directly solving complex time-domain equations. In mechanical engineering, it is used to model vibrations and control mechanical systems. The Laplace transform also plays a crucial role in signal processing, enabling the analysis of filters and systems in the s-domain. Furthermore, it has applications in probability theory, solving integral equations, and modeling various physical phenomena such as heat conduction and fluid dynamics. The inverse Laplace transform allows results to be interpreted in the time domain, ensuring practical utility. Its ability to handle initial conditions systematically makes it ideal for both theoretical analysis and real-world problem-solving. Overall, the Laplace transform serves as a bridge between the time and frequency domains, offering a streamlined approach to solving linear differential equations and modeling dynamic systems effectively.
Keywords: Laplace Transform, Inverse Laplace Transform, Complex variable (s), Differential equations.

EFFECT OF SOLID- STATE FUNGAL FERMENTATION ON THE BIOACTIVE SUBSTANCES IN THE POD OF ALBIZIA LEBBECK

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ABSTRACT
Fermentation has been variously and positively engaged in the development of edible food material from unconventional sources and their nutritional enhancement. *Albizia lebbeck* is an underutilized leguminous tree with pods that hold a potential as a sustainable alternative feed source for livestock. This research was aimed at "Improving the nutritional status of *Albizia lebbeck* pods through fungal solid-state fermentation. Mature, dried *Albizia lebbeck* pods were collected from the premises of Ministry of Agriculture Ilorin, Ilorin, Kwara State, Nigeria. Isolation of predominant fungus from naturally fermented *Albizia lebbeck* pod was done using standard method. Isolated fungus was characterized and identified with macroscopic and microscopic features. The fungal spore suspension was used in pure culture for the solid-state fermentation of the pulverized pod for five days under laboratory conditions. The effects of fermentation on the nutritional factors of the pod were determined on the proximate content, phytochemical content, mineral composition, antioxidant status and the amino acid profile using standard methods. The isolated fungus was identified as *Aspergillus terreus*. The nutritional status of the pod was enhanced in the proximate content, macro minerals. Phytochemical; Tannin content increased from 5.99 ± 0.24 to 9.74 ± 0.06. Protein increased from 6.11 ± 0.00 to 10.50± 0.00 %, Magnesium increased from 183.75 ± 1.15 to 196.57 ± 3.68 ppm, Calcium increased from 55.00 ± 0.08 to 139.85 ± 3.18 ppm, total antioxidant capacity increased from 32.56 ± 0.021 to 64.39 ± 0.21, Amino acid; Leucine increased from 1.84 ± 0.06 to 3.17 ± 0.09. Fermentation of *Albizia lebbeck* pods by *Aspergillus terreus* was found to have desirable impact on the nutritional status as well as the enhancement of other bioactive substances like the antioxidant and amino acid content, the fermented pod has the potential to be an alternative beneficial source of food or feed supplement.

Keywords: Albizia lebbeck, Aspergillus terreus, Solid-State Fermentation, Nutritional Enhancement.

THE EVOLUTION OF DENTAL ZIRCONIA: FROM CONVENTIONAL TO HYPER-TRANSLUCENT

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ABSTRACT
Zirconia is one of the materials with several advantages including excellent mechanical and biological behaviors that provide numerous indications in various clinical situations. Because the opaque appearance of zirconia negatively affects the aesthetic outcome, layering materials have been proposed to mask this appearance. However, porcelain chipping is considered one of the most common technical problems in veneered zirconia crown. To overcome the problem of poor optical properties, translucent monolithic zirconia was introduced to fabricate multi-unit monolithic crown without increased risk of porcelain fracture or reduced aesthetic properties of the core material. However, this material must be further studied in vitro and in vivo to determine its long-term ability to maintain its exceptional properties. The aim of this paper is to provide an overview of the dental zirconia revolution, including its types, properties, applications and cementation procedures.
Keywords: Zirconia, dental prostheses, ceramics, translucency, cementation, monolithic.

SYNTHESIS, HYDROLYSIS, AND COX-2/15-LOX INHIBITORY POTENTIAL OF 4-ACETAMIDOPHENYL 4-BROMOBENZOATE DERIVATIVES

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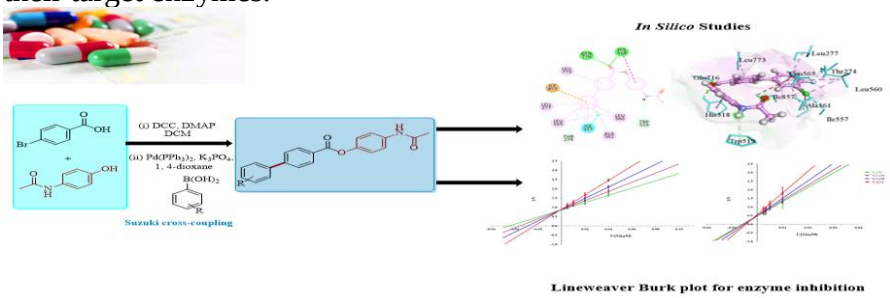
ABSTRACT

Inflammation is a complex yet vital defense mechanism in the human body, playing a significant role in both protection and the development of various diseases. Among the key enzymes involved in inflammatory pathways, cyclooxygenase-2 (COX-2) and 15-lipoxygenase (15-LOX) catalyze the metabolism of arachidonic acid and are strongly implicated in the onset and progression of numerous inflammatory disorders. Simultaneous inhibition of both COX-2 and 15-LOX represents a promising therapeutic strategy, offering enhanced anti-inflammatory efficacy and minimized off-target effects compared to conventional NSAIDs. In the present study, we designed and synthesized a series of arylated carboxylate acetaminophen analogues as potential dual COX-2/15-LOX inhibitors. Among these, compounds **5b**, **5d**, and **5e** demonstrated moderate COX-2 inhibitory activity with IC_{50} values of 1.44 ± 0.10, 1.80 ± 0.14, and 2.39 ± 0.11 μM, respectively. Notably, compound **5c** exhibited potent COX-2 selectivity with an IC_{50} of 0.18 ± 0.05 μM, outperforming the reference drug celecoxib (IC_{50} = 0.33 ± 0.11 μM). In comparison to quercetin—a standard 15-LOX inhibitor with an IC_{50} of 15.8 ± 0.61 μM—all synthesized analogues showed markedly improved 15-LOX inhibitory activity. Compound **5c** emerged as the most potent 15-LOX inhibitor, with an IC_{50} of 0.14 ± 0.18 μM. Furthermore, molecular docking studies supported the in vitro findings, revealing specific binding interactions between the synthesized derivatives (**5a–5f**) and their target enzymes.



Keywords: Paracetamol derivatives, COX-2 inhibitors, 15-LOX-inhibitors, Ester/Amide hydrolysis, Molecular Docking studies

SUSTAINABLE ALTERNATIVE FOR TEXTILE COLORATION USING PHENOLIC CONTENTS FROM DIFFERENTS COMBINATION *OF EUCALYPTUS CAMLDULENSIS* AND *CINNAMOMUM VERUM*

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ABSTRACT
A dye is nothing but a colored substance that has an affinity to the substrate to which it is being applied.Colour is one of the elements of nature that makes human life more aesthetic and fascinating. There are currently many differents dye extraction processes, including Solvent , aqueous, enzymatic extraction, etc. Dye could be natural dye derive from plants and animals and Artificial dye from chemical industry. Environment pollution is emerging as an alarming issue all over the world.The textile industry regards as the most polluting, as water pollution caused by effluents. These effluents contain toxic chemicals like carcinogenic amines and mutagens in Azo dyes, heavy metals, several natural products have been reported to possess dyeing abilities; Synthetic dyes are allergic, carcinogenetic, non biodegradable and difficult to prepare and cannot be dispose off easily. Though phenolic compound has been showing Natural dyes are Nontoxic, Biodegradable, nonallergic, non carcinogenetic easy to prepare and can be dispose off easily. Eucalyptus camldulensis (E) was blended with Cinnamomum verum (C) in different ratio to attained three differents hybrid forms. The extracts blended in the following ratios and labelled accordingly; 1:1 labelled CS_1, 4:1 labelled CS_2 and 1:4 labelled CS_3. A phytochemical screening revealed presence of compounds responsible for dyeing properties in the crude extracts of Eucalyptus camldulensis,Cinnamomum verum and blended portions.phytochemical analysis shows flavonoids, quinones, tannins, carotenoids, alkaloids, coumarins. This research reveal phenolic contents in both Eucalyptus camldulensis and Cinnamomum verum.

Keywords: Natural Dyes, Classification, Extraction-Method, Application, Eco-Friendly.

THERMAL PROPERTIES OF FERROGELS BASED ON AGAR GUM AND OCTENYL SUCCINIC ANHYDRIDE (OSA) STARCH

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ABSTRACT
Recent advances in the chemical, physical, and biological fields combined with the growing needs in the biomedical and pharmaceutical sectors have led to new developments of nanocomposite hydrogels for diverse applications. New polymer chemistries and formulations as well as manufacturing and processing techniques are supported by improved instrumentation that can measure and manipulate matter at the nanoscale.The melting point (*T*m) is determined as the temperature at which a polymer changes from a crystalline state to a viscous flow state, unlike low molecular weight substances, in which this process takes place in a jump-like manner. The objective of this work is to prepare nanocapsules of MNPs coated with OSA starch present in a rigid network of Agar to obtain a nanocomposite gel (ferrogel). The ferrogels then obtained must have a thermal stability, an interesting stiffness with respect to shear or temperature scanning, and uniform surface morphology with a minimum of clusters of magnetic particles. For this reason, the evaluation of the effect of the concentration of MNPs coated with PNiPAAm on the OSA starch/Agar system is important for developing synergistic interactions, leading to stable systems that can be used as biomaterials in nanomedecine.
Keywords: Agar gum, ferrogels, magnetic nanoparticles, OSA starch, rheology, thermal properties.

INVESTIGATION OF THE OPTICAL PROPERTIES OF SNO_2 USING DFT WITH HUBBARD CORRECTIONS

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ABSTRACT
First-principles calculations were performed to investigate the structural and optical properties of the SnO_2 compound using Perdew-Zunger (PZ) exchange-correlation functionals within the framework of density functional theory (DFT), as implemented in the Quantum Espresso code. The optimized values of the lattice parameters, a = 4.763 Å and c = 3.221 Å, are in reasonable agreement with the available experimental data. Optical properties including dielectric function, refractive index, absorption coefficient, reflectivity and electron energy loss were also calculated and analyzed.The spectra obtained for the above-mentioned optical magnitudes using the standard DFT approach show significant deviations from experimental measurements. However, by incorporating the onsite Hubbard U and intersite Hubbard V corrections, the calculated optical responses show much better alignment with the experimental data.
Keywords: SnO_2, Optical properties, DFT, Hubbard corrections.

A COMPUTATIONAL STUDY FOR STRUCTURAL MODELING AND FUNCTIONAL ANNOTATION OF AN UNCHARACTERIZED PROTEIN FROM *XANTHOMONAS ORYZAE* PV. *ORYZAE* INVOLVED IN PHOTORESPIRATION

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ABSTRACT
Xanthomonas oryzae pv. oryzae (Xoo) is a bacterial pathogen that causes bacterial leaf blight (BLB) in rice, leading to substantial reductions in crop yield. Rice bacterial blight has a strong potential to spread rapidly and severely impacts high-yielding rice varieties in both tropical and temperate regions. The bacterium survives on dead plant material and seeds, likely spreading most effectively between plants through irrigation water or storm runoff in paddy fields. This study seeks to analyze the Xoo protein sequence and conduct structure-based functional assessments. It involves examining physicochemical properties, predicting subcellular localization and solubility, identifying domains and motifs for targeted functional insights, conducting gene ontology analysis, exploring protein-protein interaction networks, performing multiple sequence alignment, and predicting as well as analyzing both secondary and tertiary protein structures. The physicochemical analysis indicated that the protein is acidic, stable, thermally resistant, and hydrophilic. The subcellular localization and solubility prediction suggested that the protein is cytoplasmic and soluble. The target protein includes a catalase enzyme that converts hydrogen peroxide into water and molecular oxygen, aiding in photorespiration, enhancing drought stress resistance, and improving tolerance to phytotoxicity. Gene ontology analysis has clarified the protein's involvement in various cellular, molecular, and biological processes, while the PPI network reveals interactions between the specified protein and ten other proteins. Multiple sequence alignment showed the evolutionary relationship between the identified protein and the corresponding catalase proteins. The analysis of the secondary structure revealed that the random coil was the most prominent structural component, followed by the alpha helix and extended strand. Additionally, the protein's homology modeling was revealed using two different programs: I-TASSER and SWISS-MODEL. Upon reviewing the homology modelings, the results indicated that SWISS-MODEL provided a more accurate configuration. The functional protein is linked to photorespiration and could be targeted for developing new therapeutic strategies to combat infections caused by Xanthomonas oryzae pv. oryzae.

Keywords: Xanthomonas oryzae pv. oryzae, Bacterial leaf blight, Destructive disease, Rice, Catalase isozyme C, Catalase protein, Photorespiration.

SYNTHESIS AND ANTIMICROBIAL ACTIVITY OF CHOLIC ACID HYDRAZONE ANALOGUES

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ABSTRACT

Hydrazones constitute an important class of pharmaceutical compounds with a wide range of therapeutic properties. They are distinguished by their azomethine -NH-N=CH functional group. These biologically active molecules have garnered considerable interest from medicinal chemists. Furthermore, bile acids which are amphiphilic molecules, undergo biological recycling during enterohepatic circulation. These naturally occurring ligands are specifically recognized by hepatic cells, making them an important area of study. Steroid-based derivatives have demonstrated significant antimicrobial activity, presenting a novel and potentially powerful approach to combating bacterial resistance. Quiet of interest in relation to the synthesized hydrazones is the formation of two rotamers *s-cis.E* and *s-trans.E.* Most compounds showed stronger antimicrobial activity against Gram-positive bacteria than Cefaclor and Cefixime.

STUDY OF *IN VITRO* PROPAGATION AND SELECTION FOR SALT TOLERANCE OF LOCAL OPUNTIA CACTUS

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ABSTRACT
Opuntia cactus is a horticultural crop, which is extensively used as food for humans and feed for animals in many countries of the world. This crop has widely adapted to different parts of Tunisia and is an integral part of the culture and economy of arid and semi-arid zones of the country. Recently, to fulfil the demand for large-scale cultivation in a short period by rapid mass multiplication, *in vitro* organogenesis and embryogenesis experiments were conducted with the aim of developing a protocol for *in vitro* propagation of local cactus from areole explants and *in vitro* selection of local cactus for salinity tolerance and resistance. For the first experiment, a reliable strategy was followed for micropropagation of *Opuntia ficus-indica* (L.) and *Opuntia robusta* L. cactus in the presence of the growth regulators, 6-benzylaminopurine (BAP) and metatopolin (mT), at four different concentrations (0.5, 1, 2 and 3 mg/l) and via callogenesis with 2,4-D and picloram at 2, 4, 6 and 8 mg/l. Results of the first experiment revealed that best values of shoot evolution for the 2 cactus species was recorded on media supplemented with BAP, mainly. Media with mT lead to vitroplants with less quality. *Opuntia robusta* vitroplantlets show better evolution results than *Opuntia ficus-indica* vitroplantlets. In the second experiment, large and compact calli were initiated on MS medium enriched with 2 and 4 mg/l picloram. For salinity stress tolerance, a decreasing pattern in number and quality of cactus shoots and calli were observed with increasing salinity levels and widely affected at 8 and 10 g/l NaCl. On media with 2, 4 and 6 g/l of NaCl, plantlets show a normal morphologic evolution indicating that cactus can tolerate relatively high salinity levels.
Keywords: Opuntia cactus, mT, *in vitro* propagation, NaCl, salinity stress.

TRANSFORMATION ALGORITHM FOR SOLVING LINEAR ORDINARY DIFFERENTIAL EQUATION INTO INTEGRAL EQUATIONS USING BOUBAKAR POLYNOMIALS

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ABSTRACT
In this research, we employ computational algorithms for solving linear ordinary differential equations of second-order initial value problems (IVPs), using Boubakar polynomials as basis functions. Also, standard and Chebyshev-Gauss-Lobatto collocation points were respectively, used to collocate the approximate solution. The ODEs were first converted to integral equations, and the basis function was substituted to obtain a set of linear algebraic equations, which then formed equations that were solved through Maple software package**.** Numerical examples were provided to demonstrate the method's performance for various orders, as well as comparisons with exact and approximate solutions for various orders. However, it was observed that as the degree of approximation N increased, the results were very close to exact solution, as can be seen from the tables of errors and graphical presented.
Keywords: Boubakar polynomials, Chebyshev-Gauss-Lobatto collocation points, Standard collocation points, Initial value problem, Integral equations

THE ANTIMICROBIAL ACTIVITY OF MESOPOROUS MATERIALS TYPE SILVER/SBA15

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ABSTRACT
Porous materials have been intensively studied with regard to technical applications as catalysts, catalyst supports, and adsorbents. According to the IUPAC definition, porous materials are divided into three categories: microporous (pore size 50 nm) materials .The advantages of mesoporous materials are summarized as follows: (a) Mesoporous materials have highly ordered and controllable size which enable the sizeselective adsorption of small molecules but the size-exclusion of larger molecules, providing molecular weight cutoff in sample enrichment [1] (b) Mesoporous materials have high surface areas and large pore volumes which provide sufficient capacity for the adsorption of reactants.(c) The framework of mesoporous materials can be various oxides, including silica, alumina, or transition metal oxides [2]. The transition metal oxides are particularly important among non-silica mesoporous materials because they possess d-shell electrons confined to nanosized walls, redox active internal surfaces, and connected pore network [3].Additionally, the mesoporous structure of SBA-15 allows for easy accessibility of reactants to the active sites on the silver nanoparticles, further enhancing the catalytic activity. The tunable pore size also allows for the possibility of size-selective catalysis, where only molecules of a certain size can access the active sites.
Key words : mesoporous materials , d-shell electrons , SBA15

A COMPREHENSIVE *IN VITRO* AND COMPUTATIONAL ASSESSMENT OF BIOLOGICAL ACTIVITIES OF PHYTOCONSTITUENTS IN ENDOPHYTIC BACTERIAL CRUDE EXTRACT DERIVED FROM THE LEAVES OF *ENHYDRA* FLUCTUANS

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ABSTRACT

The research explores the bioactive properties of endophytic bacterial secondary metabolites from *Enhydra fluctuans* Lour., a medicinal plant with antioxidant and antimicrobial benefits, identifying bioactive compounds through in vitro and in silico analysis. Fresh, mature leaves of E. fluctuans were collected, disinfected, and analyzed. Bacteria were first identified morphologically then by use of 16S rRNA gene sequencing. Metabolites of bacteria were extracted using ethyl acetate and evaluated for antibacterial activity using the disc diffusion method and antioxidant activity using the DPPH radical scavenging method. GC-MS was used to identify volatile bioactive substances. A single endophytic bacterium, *Pseudomonas campi* (NR_181172.1) was isolated from leaves of *E. fluctuans*. The antibiotic susceptibility pattern indicated that the isolate was mostly sensitive to Ciprofloxacin (5 µg). Its ethyl acetate crude extract of exhibited moderate antibacterial activity at 500 µg/disc, with inhibition zones of 13.4±0.205 mm against *Staphylococcus aureus* compared to standard kanamycin (30 µg/disc). Antioxidant activity was also observed with an IC50 value of 61.66 µg/ml, compared to ascorbic acid's IC50 of 17.38 µg/ml. Using GC-MS, 19 bioactive compounds were identified, with Phenol, 3,5-bis(1,1-dimethylethyl)-;1,9-Diazaspiro (4,4) nonane-2,8-dione and Octacosanol being the major constituents. *In silico* analyses revealed that 9,10-anthracenedione, 2-[(tert.-butylamino) methylcarbamoyl] exhibited strong antibacterial and antioxidant potential, with maximum binding affinities towards the proteins MurD ligase (-9.8 kcal/mol) and Myeloperoxidase (-9.6 kcal/mol), respectively. Almost all molecules were non-toxic, and simulations conducted over 100ns verified stability. These findings emphasize the potential of bacterial endophytes as a source of new lead compounds. Further investigation is required to explore their pharmacological activities.

Keywords: Endophytic bacteria, antibacterial, antioxidant, GC-MS, In silico, Drug discovery.

PRODUCTION OF POLYHYDROXY BUTYRATE BY AGRICULTURE WASTE USING SOLID STATE FERMENTATION

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ABSTRACT
Polyhydroxybutyrate (PHB), a bioplastic, has attracted the attention in the recent years due to its ability to replace the polyethylene, a non-biodegradable plastic. The aim of the present research work was to evaluate the potential of different agricultural wastes like wheat bran, rice polishings and corn cob for the synthesis of PHB by *Bacillus thuringiensis* FCBP-SB-0002 using solid state fermentation. Optimization of different components of basal media and various physical parameters was also performed. Maximum PHB yield (420 mg/100g) was achieved on fermentation of rice polishing at substrate water ratio of 10:36 at 72 hours of incubation time, pH 7, temperature of 30^0C by addition of 1 mL inoculum. Addition of different optimum levels of ionic salts (1.5% of $KH_2PO_4.2H_2O$, 2% $MgSO_4$ and 2% NaCl) and nitrogen sources (0.75% urea and 1% corn steep liquor) increased the PHB production to 680 mg/100g respectively. Identification of PHB was done by FTIR analysis and was found to be 98% pure in comparison to standard by spectrophotometric method. The outcomes of the present study indicated that agricultural wastes can be used for the cheap production of bioplastic. This strategy will also help to reduce environmental pollution caused due to disposal of this waste material.
Key words: Polyhydroxybutyrate, Agricultural waste, *Bacillus thuringiensis,* optimization, solid state fermentation

EXPLORING NOVEL SIMPLE HYDRIDE PEROVSKITES FOR HYDROGEN STORAGE USING FIRST-PRINCIPLES CALCULATIONS

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ABSTRACT
Materials of the perovskite type could be a good option for applications involving the storage of hydrogen. In this work, the structural, electrical, mechanical, hydrogen storage, and thermodynamic characteristics of cubic perovskite-type hydride compounds KXH_3 (X = Mn, Fe) were examined using the density functional theory (DFT). The structural optimization results show that both compounds have negative formation energies, indicating that they are both thermodynamically stable. Their mechanical stability was also been studied through the computation of the elastic constants and other polycrystalline mechanical properties like bulk modulus, Poisson's ratio, etc. Both compositions exhibit metallic behavior, according to the electronic band structure and density of states of KXH_3 (X = Mn, Fe) perovskites. Their thermodynamic properties were assessed using the quasi-harmonic Debye model over a large temperature (0 to 1000 K) and pressure (of 0 to 25 GPa) range. Gravimetric hydrogen storage capacities of KXH_3 (K = Mn, Fe) are 3.021 wt% and 2.994 wt%, and their desorption temperatures are 532.994 K and 411.188 K, respectively. These properties are of considerable interest for solid hydrogen storage materials.
Keywords: DFT; Perovskite hydrides; Hydrogen storage; Thermodynamic properties; Elastic constants; Desorption temperature.

ADVANCING CLIMATE-RESILIENT AGRICULTURE: CROP IMPROVEMENT, BIOTECHNOLOGY, AND SUSTAINABLE FARMING FOR FOOD SECURITY

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ABSTRACT
Climate-resilient agriculture is an essential strategy for adapting to the challenges posed by climate change, including rising temperatures, unpredictable rainfall, droughts, and extreme weather events. Crop improvement plays a critical role in developing agricultural systems capable of withstanding these environmental stresses while ensuring global food security. The primary goal of climate-resilient crop improvement is to enhance the genetic potential of crops to tolerate various abiotic stresses, such as drought, heat, salinity, and flooding, without compromising yield or nutritional quality. Advancements in traditional breeding techniques, coupled with modern biotechnological tools, are central to this effort. Approaches such as marker-assisted selection (MAS), genomic selection, and gene editing technologies like CRISPR-Cas9 enable the precise development of crops with traits suited to changing climatic conditions. These techniques can accelerate the breeding of crops that are more efficient in water and nutrient use, more resistant to pests, and better adapted to fluctuating climates. In addition to genetic improvements, agro-ecological practices such as crop rotation, intercropping, and conservation tillage further support climate resilience by enhancing soil health and reducing vulnerability to extreme weather events. The integration of climate-resilient crop varieties with sustainable farming practices is crucial for maintaining productivity in the face of climate variability. Ultimately, climate-resilient agriculture offers the potential to improve food security, reduce poverty, and support sustainable agricultural systems by developing crops that are more adaptable to the challenges of a changing climate, thus contributing to the long-term stability of global food production.
Keywords: Climate-resilient agriculture, Crop improvement, Abiotic stresses, Biotechnology, Sustainable farming

THE IMPACT OF THE DROUGHT ON THE AGRICULTURE IN THE HODNA RIVER BASIN

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ABSTRACT
Drought is one of the major challenges facing agriculture worldwide. As a result of climate change, the frequency and intensity of drought episodes are increasing, compromising agricultural yields, food security and farmers' livelihoods. In the face of this growing threat, artificial intelligence (AI) is emerging as a powerful tool for mitigating the effects of drought on agriculture. By analysing meteorological data, modelling soils and predicting yields, AI techniques can optimise the use of water resources, anticipate periods of water stress and improve crop resilience. This work explores the impact of drought on agriculture and highlights the essential role of AI-based technologies in meeting this challenge.
Keywords: Agriculture, drought impact, AI tectonics, Hodna river.

COMPUTER MODELING OF HYDROELASTIC VIBRATIONS OF A BLADE UNDER FUZZY LOADING CONDITIONS

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ABSTRACT

Modern engineering equipment operates under significant service loads, including intense mechanical forces and elevated temperatures. Such operating conditions impose strict requirements on the strength and reliability of structural components. Therefore, already at the design stage, there is a pressing need for a detailed evaluation of the strength and dynamic characteristics of individual structural elements to ensure their safe and stable performance throughout the entire service life.

Traditionally, experimental methods are widely used to obtain these characteristics. They allow for reasonably accurate estimation of key structural parameters. However, conducting real-world experiments, especially under complex conditions, is costly in both financial and resource terms—and in some cases, also hazardous. As a result, approaches based on computer modeling of deformation and vibration processes in structural components are becoming increasingly relevant.

A major challenge in such analyses lies in the difficulty of accurately defining the parameters of external loading acting on the structure. Often, these parameters are uncertain or variable, necessitating the inclusion of uncertainties in the mathematical modelling [1]. This work proposes an effective approach for analysing hydro-elastic vibrations of a blade in a reversible-blade hydraulic turbine. The method combines potential flow theory for describing fluid motion with elements of fuzzy logic. At the initial stage, the problem of forced vibrations is solved within a deterministic framework. The fluid is modelled as ideal (i.e., inviscid) and incompressible, and its motion induced by small oscillations of the elastic element is assumed to be irrotational. This allows the introduction of a fluid velocity potential $\Phi(x,y,z,t)$, which satisfies Laplace's equation.

To solve the problem, the given nomal modes method is used. The blade's vibations are represented as a combination of its natural modes, neglecting the influence of the added mass of the fluid. The fluid pressure on the surface of the blade is determined by solving a hypersingular integral equation, obtained by representing the unknown velocity potential using a double-layer potential. The numerical solution of this hypersingular equation is performed using the boundary element method, with the unknown density function approximated by constants over the boundary elements. Then loading parameters were fuzzified.

NANOCOMPOSITE HYDROGELS: FABRICATION, CHARACTERIZATION AND BIOMEDICAL SCREENING STUDIES

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ABSTRACT

Nanoparticle-based hydrogel has been synthesized and evaluated for advanced biomedical applications including antibacterial, anticancer and wound healing functionalities. The hydrogel was fabricated using polyvinyl alcohol (PVA), chitosan and lignin mediated nanocomposites as the primary components. The resultant nanocomposite and hydrogel were characterized using UV-Visible, FTIR, TGA and XRD techniques to confirm its composition and structural integrity. In the context of antibacterial studies, PVA-CS/L@CdZnO hydrogel exhibits superior bactericidal activity as compared to CdZnO and L@CdZnO nanocomposites, effectively inhibiting *S.aureus*, *B.subtilis*, and *E.coli*. Antioxidant assays showed remarkable efficacy, with 89% DPPH free radical scavenging activity and a reducing power absorbance of 0.68. Furthermore, wound healing studies conducted on a rat model, the hydrogel achieved 91% wound closure within 10 days, significantly surpassing the 61% closure observed in the control group. Additionally, the hydrogel exhibited

50% anticancer activity against MCF-7 breast cancer cell lines, showcasing its potential in oncological applications. These results underscore the multifunctional potential of the PVA-CS/L@CdZnO hydrogel, positioning it as a promising candidate for various biomedical applications, including antibacterial, antioxidant, anticancer, and wound healing therapies.

REVIEW ON IMMUNIZATION AND VACCINE

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ABSTRACT

Immunization is one of the most effective public health strategies to prevent infectious diseases, saving millions of lives annually. Vaccines work by stimulating the immune system to recognize and combat pathogens, thus providing immunity without causing the disease itself. This review explores the history, current developments, and challenges in immunization and vaccine technology. We examine the principles of vaccine formulation, including live-attenuated, inactivated, subunit, and mRNA vaccines, alongside emerging technologies like nanoparticle-based vaccines and adjuvants. The paper also delves into global vaccination strategies, addressing issues such as vaccine hesitancy, access in low-resource settings, and the impact of vaccination on herd immunity. Finally, the review highlights the critical role of immunization in combating pandemics, with a focus on the recent COVID-19 vaccine development. Ongoing research continues to refine vaccine efficacy, safety, and accessibility, promising to enhance global health outcomes.

TİCARİ ARAÇLARDA ALÜMİNYUM MENTEŞE VE ÇELİK GÖVDE ARASINDAKİ KONTAK KOROZYONUNUN FARKLI KORUMA YÖNTEMLERİ İLE İNCELENMESİ

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ÖZET
Bu çalışmada, ticari araçlarda kullanılan alüminyum menteşe ile çelik araç gövdesi arasındaki galvanik temas sonucu oluşabilecek kontak korozyonu, farklı koruma yöntemleri kullanılarak incelenmiştir. Çalışma kapsamında menteşe gövdeleri 6082 T6 alüminyumdan, menteşelerin araç gövdesine bağlandığı plakalar HX380LAD+Z (Z140) galvanizli çelikten ve kapı tarafındaki plakalar ise 5182 alüminyumdan hazırlanmıştır. Koruma yöntemi olarak menteşe yüzeylerine SurTec 650, kataforez kaplama ve kaplamasız seçenekler uygulanmıştır. Ayrıca menteşe ile plaka malzemeleri arasına Teroson RB81, Superlite Green Seal ve Superlite Green Seal + ek sac plaka gibi arayüz çözümleri yerleştirilerek galvanik etkileşim azaltılmaya çalışılmıştır. Numuneler, ASTM B117 ve WSS-M1P85-B5 standartlarına uygun şekilde 96 saat beyaz pas ve 360 saat kırmızı pas oluşumunu değerlendirecek şekilde tuz sisi testine tabi tutulmuştur. Test sonrası numuneler görsel muayene ve kütle kaybı yöntemi ile analiz edilmiştir. Elde edilen sonuçlara göre, SurTec 650 ve kataforez kaplamalı menteşeler korozyona karşı yüksek dayanım göstermiştir. Bununla birlikte, kataforez kaplamalı numune araç gövdesi ve kapı plakasıyla montajlanmadan test edilmiştir. Kaplamasız menteşe numuneleri ise korozyon testlerinde yetersiz performans sergileyerek başarısız olmuştur. Ara bağlantı malzemeleri, kontak korozyonunun azaltılmasında sınırlı düzeyde katkı sağlamış, özellikle yüzey kaplamalarının koruma performansı üzerinde belirleyici olduğu tespit edilmiştir.
Keywords: Galvanik Korozyon, Alüminyum-Çelik, Yüzey Kaplama, Tuz Sisi Testi, Ticari Araç Menteşeleri, Kontak Korozyon

INVESTIGATION OF CONTACT CORROSION BETWEEN ALUMINUM HINGES AND STEEL BODY IN COMMERCIAL VEHICLES USING DIFFERENT PROTECTION METHODS

ABSTRACT

In this study, contact corrosion that may occur as a result of galvanic contact between aluminium hinges used in commercial vehicles and steel vehicle body was investigated using different protection methods. Within the scope of the study, the hinge bodies are made of 6082 T6 aluminium, the plates where the hinges are connected to the vehicle body are made of HX380LAD+Z (Z140) galvanised steel and the plates on the door side are made of 5182 aluminium. As a protection method, SurTec 650, cataphoresis coating and uncoated options were applied to the hinge surfaces. In addition, interface solutions such as Teroson RB81, Superlite Green Seal and Superlite Green Seal + additional sheet metal plate were placed between the hinge and plate materials to reduce galvanic interaction. The specimens were subjected to salt fog test to evaluate the formation of white rust for 96 hours and red rust for 360 hours in accordance with ASTM B117 and WSS-M1P85-B5 standards. After the test, the samples were analysed by visual inspection and mass loss method. According to the results obtained, SurTec 650 and cataphoresis coated hinges showed high corrosion resistance. However, the cataphoresis-coated specimen was tested without mounting with the vehicle body and door plate. The uncoated hinge specimens performed poorly and failed the corrosion tests. The interconnection materials made a limited contribution to the reduction of contact corrosion, especially the surface coatings were found to be decisive on the protection performance.

Keywords: Galvanic Corrosion, Aluminum-Steel Contact, Surface Treatment, Salt Spray Test, Commercial Vehicle Hinges, Contact Corrosion

FULL TEXTS

SIX-YEAR TREND OF RED LENTIL PRODUCTION IN TURKIYE: CULTIVATION AREAS, PRODUCTIVITY, AND MARKET BALANCE

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ABSTRACT
Red lentil is one of the key legume crops with strategic importance for both human nutrition and agricultural production in Türkiye. This study analyzes the trends in red lentil cultivation, production, yield, and market balance in Türkiye between 2018 and 2023. The data reveal notable regional disparities and fluctuations over time. Şanlıurfa consistently held the largest share of cultivation areas, accounting for nearly half of the national total in 2023. Although total cultivation area dropped significantly in 2020, it peaked in 2022 at almost 3 million decares before slightly declining in 2023. Production followed a similar pattern, reaching its lowest point in 2021 (228,000 tons) and its highest in 2023 (424,000 tons), mainly due to increased yield and expanded cultivation in southeastern provinces. Yield also varied considerably, with a national low of 92 kg da^{-1} in 2021 and a recovery to 153 kg da^{-1} by 2023. Despite rising domestic production, Türkiye remains reliant on imports to meet internal demand, as shown by the sharp increase in lentil imports, which grew to 869,000 tons in 2022/23. The self-sufficiency rate fluctuated accordingly, dropping to 57% in 2021/22 and improving to 85.9% in the following year. These findings underscore the influence of agricultural policies, climate conditions, and global market dynamics on red lentil production, highlighting the need for regionally targeted agricultural strategies to ensure food security and a favorable trade balance.
Keywords: Red lentil, cultivation area, production, yield, self-sufficiency ratio

1. INTRODUCTION

Red lentil (*Lens culinaris* Medik.) is one of the essential crops in Türkiye, holding strategic importance both in traditional dietary habits and in pulse cultivation. Due to its rich nutritional content, high in protein, complex carbohydrates, iron, and folate, red lentil plays an indispensable role in human nutrition. Furthermore, as a legume capable of fixing atmospheric nitrogen, it contributes to improved soil fertility and is thus considered a vital component of sustainable agricultural systems (FAO, 2021; IPCC, 2022). Although Türkiye ranks among the leading producers of red lentils globally, recent years have witnessed significant fluctuations in terms of cropping patterns, yield levels, and foreign trade balance.

Data from the Turkish Statistical Institute (TURKSTAT, 2025) for the 2018–2023 period reveal that red lentil production in Türkiye is concentrated in specific provinces and follows a fluctuating trend in terms of both cultivated area and total output. Given the multitude of factors influencing production, ensuring stability in red lentil farming appears to be a considerable challenge. Despite a decline in yield observed in 2021, the expansion trend in cultivated areas has resumed in 2022 and 2023. However, climatic variability, market prices, import policies, and government support mechanisms have played a decisive role in shaping production decisions over the years (Parfitt et al., 2010; Wheeler & von Braun, 2013).

In this context, to understand Türkiye's current situation in red lentil production and to develop future-oriented sustainable agricultural policies, it is essential to conduct a comprehensive analysis that includes cultivated area, production volume, yield levels, and balance components (imports, exports, stocks, and self-sufficiency rates). Especially for crops like red lentils that are highly sensitive to climate change and closely tied to international trade, production planning should not be limited to increasing supply alone; it must also incorporate strategic decisions aimed at reducing regional productivity disparities and strengthening supply-demand balance (FAO, 2021; Lobell & Gourdji, 2012; IPCC, 2022). This section presents a multidimensional evaluation of the current state of red lentil cultivation in Türkiye based on official data from the 2018–2023 period.

2. CULTIVATED AREA OF RED LENTIL IN TÜRKIYE

Data on red lentil cultivation areas in Türkiye between 2018 and 2023 reveal significant regional disparities and a fluctuating trend over the years. The Southeastern Anatolia Region, particularly the province of Şanlıurfa, has emerged as a strategic center for red lentil cultivation. In 2023, Şanlıurfa alone accounted for 47.22% of the total red lentil cultivation area in the country. This figure clearly illustrates the province's dominant position in red lentil production. While the cultivated area was approximately 930,000 decares in 2018, it peaked at 1.35 million decares in 2022 before declining slightly to 1.31 million decares in 2023 (Table 1). The increase and subsequent fluctuation in cultivated area can be attributed to the expansion of irrigation infrastructure under the Southeastern Anatolia Project (GAP), government support policies, and growing market demand for lentils (FAO, 2020; FAO, 2021; IPCC, 2022).

Following Şanlıurfa, the provinces of Diyarbakır and Mardin also stand out with extensive cultivation areas. Diyarbakır experienced a remarkable increase, reaching 786,000 decares in 2022. In contrast, Mardin exhibited a continuous downward trend, with cultivated area declining from 302,000 decares in 2018 to 173,000 decares in 2023 (Table 1). These differing trends are closely related to farmer preferences, yield expectations, and regional climatic conditions (Lobell et al., 2011; Lobell & Gourdji, 2012). Meanwhile, provinces such as Batman and Siirt have shown an upward trend in the cultivation of red lentils. In particular, Siirt nearly doubled its area from 73,000 decares in 2018 to around 150,000 decares in 2023. This trend indicates growing interest in lentil production in these provinces and suggests a shift in the regional distribution of cultivation.

Outside the Southeastern region, provinces such as Konya, Gaziantep, Kilis, and Adıyaman have relatively limited areas allocated to red lentil cultivation. In these provinces, both the share of total cultivated area and year-on-year changes have been inconsistent. For example, in Konya, the cultivated area peaked at 63,000 decares in 2021 but dropped back to 37,000 decares in the following years. This suggests that while lentils may be preferred as an alternative crop in marginal areas, a stable production pattern has yet to be established. Similarly, the total cultivated area in the category of "other provinces" decreased between 2018 and 2023, indicating a growing geographic concentration of red lentil farming (Table 1).

Overall, red lentil cultivation in Türkiye declined to its lowest point in 2020 with 2.1 million decares, then rose to a six-year high of nearly 3 million decares in 2022. However, the total area fell again to 2.78 million decares in 2023, demonstrating that agricultural production, particularly red lentil farming, is susceptible to market conditions, climate variability, and agrarian policy dynamics (Parfitt et al., 2010; Wheeler & von Braun, 2013). These findings highlight the need for agricultural policies in Türkiye to be guided by strategic, regionally based planning.

Table 1. Red Lentil Cultivation Areas in Türkiye (da)

Provinces	Years					
	2018	2019	2020	2021	2022	2023
Şanlıurfa	929.902	949.719	806.000	1.188.121	1.349.231	1.313.513
Diyarbakır	681.222	632.193	536.544	576.051	786.789	696.625
Mardin	302.176	277.020	175.855	175.997	174.435	173.443
Batman	133.250	152.211	142.855	150.145	189.855	157.832
Siirt	73.388	69.618	87.532	127.545	135.510	149.995
Şırnak	30.769	39.482	116.358	112.401	118.897	70.444
Gaziantep	75.040	68.140	51.991	46.835	52.530	55.130
Konya	31.719	65.457	40.096	63.872	38.512	37.151
Kilis	37.256	33.897	34.997	33.604	34.458	34.570
Adıyaman	11.963	6.107	13.360	30.080	32.965	28.691
Other	123.967	133.917	92.627	97.344	84.936	64.128
Total	2.430.652	2.427.761	2.098.215	2.601.995	2.998.118	2.781.522

(TURKSTAT, 2025)

3. PRODUCTION OF RED LENTIL IN TÜRKIYE

Red lentil production in Türkiye between 2018 and 2023 varied across provinces and followed a fluctuating trend at the national level. In both 2018 and 2019, total production remained stable at around 310,000 tons. In 2020, production rose to 328,000 tons, indicating a positive trend. However, in 2021, production dropped sharply by nearly 30% to 228,000 tons. This significant decrease is closely linked to yield losses and reduced cultivation areas, particularly in major production centers such as Diyarbakır, Mardin, and Batman (Table 2). Adverse agricultural conditions, such as drought, disease pressure, and low price expectations, may also have contributed to this decline.

Amid this volatility, Şanlıurfa has emerged as the leading red lentil production region in Türkiye. Production in the province rose steadily from 72,000 tons in 2018 to 170,000 tons in 2023, accounting for approximately 40% of the country’s total output. This increase is strongly linked to the province's extensive agricultural lands, the adoption of modern farming techniques, and investments in irrigation systems. Türkiye saw a significant surge in red lentil production in 2022 and 2023, with national output reaching 400,000 tons in 2022 and peaking at 424,000 tons in 2023. This growth can be attributed not only to the expansion of cultivated areas but also to yield-enhancing factors such as improved fertilization, variety selection, and relatively favorable climatic conditions.

Diyarbakır remained one of the top-producing provinces after Şanlıurfa, tripling its production in 2022 to reach 131,000 tons. Similar increases were observed in smaller producing provinces such as Siirt and Batman. For example, in Siirt, production rose from 2,550 tons in 2018 to approximately 29,400 tons in 2023 (Table 2). This upward trend highlights the growing expansion of pulse cultivation in Eastern and Southeastern Anatolia and the effectiveness of regionally targeted agricultural support programs. On the other hand, the decline in production in provinces like Gaziantep and Şırnak suggests that red lentil farming in these areas lacks continuity and is more vulnerable to risk factors.

Table 2. Red Lentil Production in Türkiye (tons)

Provinces	Years					
	2018	2019	2020	2021	2022	2023
Şanlıurfa	72.053	91.287	104.010	105.386	143.691	170.766
Diyarbakır	125.216	102.977	97.461	46.298	131.701	126.221
Siirt	2.550	8.933	14.725	16.255	26.520	29.393
Batman	26.625	26.576	28.001	16.313	33.490	29.279
Mardin	41.712	40.396	31.230	12.277	24.050	26.873
Şırnak	4.415	5.465	22.396	7.972	10.318	9.218
Konya	3.307	6.832	6.120	4.215	6.557	7.717
Gaziantep	11.638	9.358	7.567	4.087	3.765	6.325
Adıyaman	2.318	1.023	2.051	3.722	4.643	4.345
Kahramanmaraş	324	299	692	1.695	3.440	3.763
Other	19.842	16.854	14.165	9.780	11.825	10.100
Total	310.000	310.000	328.418	228.000	400.000	424.000

(TURKSTAT, 2025)

The upward trend in Türkiye's red lentil production indicates that the crop has regained strategic importance in national agricultural planning. However, it remains crucial to promote resilient farming systems capable of withstanding climatic variability and to develop sustainability-focused policies, especially in regions with lower productivity (Parfitt et al., 2010; Wheeler & von Braun, 2013; FAO, 2021).

4. YIELD OF RED LENTIL IN TÜRKIYE

Red lentil yield in Türkiye exhibited significant fluctuations between 2018 and 2023, both across years and provinces. According to data from the Turkish Statistical Institute (TURKSTAT, 2025), the national average yield was 138 kg da^{-1} in 2018 but declined sharply to 92 kg da^{-1} in 2021. In the following years, it recovered and reached 153 kg da^{-1} by 2023 (Table 3). This fluctuation is attributed mainly to extreme climatic events (particularly drought), rising input costs, and changing farmer preferences in certain regions (FAO, 2021). The low yield in 2021 is considered a result not only of unfavorable climate conditions but also of shortcomings in the adoption of yield-enhancing technological and agronomic practices (FAO, 2021).

At the regional level, some provinces consistently achieved high yield values, while others experienced more volatile outcomes. For example, Kahramanmaraş reached a remarkable yield of 230 kg da^{-1} in 2021 and maintained strong performance with 223 kg da^{-1} in 2023. Similarly, Konya rebounded from a dip in 2021 to achieve 208 kg da^{-1} in 2023, well above the national average (Table 3). These achievements can be attributed to factors such as improved soil management, expanded irrigation opportunities, and the use of regionally adapted varieties (Parfitt et al., 2010; Wheeler & von Braun, 2013; FAO, 2021).

On the other hand, provinces like Siirt, Muş, and Batman exhibited more stable yield improvements. In Siirt, for instance, yield increased from 132 kg da^{-1} in 2018 to 196 kg da^{-1} in 2022 and 2023, representing nearly a 50% rise (Table 3). This growth reflects both the increasing interest of local farmers in red lentil cultivation and the effectiveness of technical

support and advisory programs. Similar trends were observed in Muş and Batman, suggesting that agricultural production in these provinces has become more resilient to external risks.

Table 3. Red Lentil Yield in Türkiye (kg da^{-1}**)**

Provinces	Years					
	2018	2019	2020	2021	2022	2023
Kahramanmaraş	114	103	149	230	217	223
Konya	113	105	153	66	170	208
Siirt	132	128	168	127	196	196
Muş	153	138	143	86	149	191
Batman	200	175	196	109	176	186
Diyarbakır	184	163	182	86	167	182
Çorum	100					174
Mardin	138	146	178	70	138	155
Isparta	165	164	160	157	152	154
Adıyaman	194	168	154	124	141	151
Mean of Türkiye	138	128	157	92	133	153

(TURKSTAT, 2025)

Conversely, key production centers such as Mardin and Diyarbakır experienced notable fluctuations in yield. In Mardin, yield dropped from 178 kg da^{-1} in 2020 to 70 kg da^{-1} in 2021, before partially recovering to 155 kg da^{-1} in 2023. In Diyarbakır, yield fell to 86 kg da^{-1} in 2021 and rose to 182 kg da^{-1} by 2023 (Table 3). These variations can be explained by factors such as drought, soil degradation, improper agricultural practices, and difficulties in accessing inputs (FAO, 2021; IPCC, 2022).

Although the national trend of yield recovery in red lentil cultivation is a positive development, the persistent high variation among provinces indicates the need for regionally differentiated agricultural policies. In provinces with lower yields, promoting farmer education, disseminating modern techniques, and encouraging the use of high-quality seeds will play a critical role in unlocking production potential (FAO, 2021; IPCC, 2022).

5. BALANCE STATUS OF RED LENTIL IN TÜRKIYE

Türkiye's red lentil balance status between the 2018/19 and 2022/23 periods exhibited significant fluctuations across key components such as production, imports, exports, and domestic utilization. At the beginning of the period, production remained stable at around 310,000 tons during the 2018/19 and 2019/20 marketing years. In 2020/21, production increased moderately to 328,000 tons. However, in 2021/22, production fell sharply to 228,000 tons, a decline largely attributed to drought conditions, rising production costs, and reduced yield levels (FAO, 2021; IPCC, 2022). As a result, the self-sufficiency ratio dropped to 57%, marking the lowest level during the period under review. On the other hand, production recovered in 2022/23, reaching 400,000 tons, which raised the self-sufficiency ratio to 85.9%, signaling a rebound in red lentil production (Table 4).

This variability in production had a direct impact on import volumes. To meet domestic demand, Türkiye conducted substantial imports of red lentils throughout the period. Imports, which stood at 318,000 tons in 2018/19, surged to approximately 869,000 tons in 2022/23, an all-time high. This sharp increase pushed the total supply to 1.26 million tons, creating a significant supply surplus. Consequently, this oversupply enabled Türkiye to achieve high export volumes as well; exports reached 496,000 tons in 2022/23, marking a substantial rise compared to previous periods (Table 4). The parallel increase in both imports and exports reflects Türkiye's dual strategy of meeting domestic demand while also maintaining a competitive position in international markets (IPCC, 2022).

Table 4. Red Lentil Balance Sheet in Türkiye

	Years				
	2018/19	2019/20	2020/21	2021/22	2022/23
Production (tons)	310.000	310.000	328.418	228.000	400.000
Post-Harvest Losses (tons)	8.060	8.060	8.539	5.928	10.400
Supply = Utilization (tons)	620.194	781.803	788.309	595.948	1.258.695
Available Production (tons)	301.940	301.940	319.879	222.072	389.600
Imports (tons)	318.254	479.863	468.430	373.876	869.095
Domestic Utilization (tons)	403.050	420.903	449.514	389.827	453.287
Human Consumption (tons)	363.806	381.247	413.098	343.653	399.981
Seed Use (tons)	29.168	29.133	25.179	36.428	41.974
Losses (tons)	10.076	10.523	11.238	9.746	11.332
Exports (tons)	341.021	310.683	276.490	314.823	496.413
Stock (tons)	-123.877	50.217	62.305	-108.702	308.995
Per Capita Consumption (kg)	4.4	4.6	4.9	4.1	4.7
Self-Sufficiency Ratio (%)	74.9	71.7	71.2	57.0	85.9

(TURKSTAT, 2025)

When examining the components of domestic utilization, human consumption represents the largest share. Per capita consumption peaked at 4.9 kg during the 2020/21 period, then declined to 4.1 kg in 2021/22, before rising again to 4.7 kg in 2022/23. Trends in human consumption are influenced not only by the traditional role of red lentils in dietary habits but also by factors such as price fluctuations, product quality, and the development of alternative protein sources (Parfitt et al., 2010; Wheeler & von Braun, 2013; FAO, 2021). Seed use and losses, on the other hand, constitute relatively minor components of total domestic utilization. Notably, seed use increased to 41,974 tons in the 2022/23 period, reflecting the expansion trend in cultivated areas (Table 4).

When stock levels are analyzed, negative stock values observed in certain years (e.g., 2018/19 and 2021/22) point to structural imbalances between production and consumption. However, the increase in stock volume to as high as 308,000 tons in 2022/23, driven by both higher production and elevated import levels, can be interpreted as a positive development for red lentil supply security. This indicates a reduction in short-term vulnerabilities in meeting domestic demand (Table 4).

The red lentil balance status in Türkiye shows that external dependency persists, and there is a need to transform the supply-demand structure toward a more production-centered model. In addition to increasing production, it is equally essential to restructure strategies for improving productivity, enhancing storage capacity, and optimizing foreign trade policies (Parfitt et al., 2010; Wheeler & von Braun, 2013; FAO, 2021; IPCC, 2022).

6. CONCLUSION AND EVALUATION

Red lentil production statistics for the 2018–2023 period reveal that this strategic pulse crop continues to hold a strong position within Türkiye's agricultural system. However, fluctuations in production, yield, and foreign trade indicators point to underlying structural vulnerabilities. In particular, the Southeastern Anatolia Region, especially the province of Şanlıurfa, has taken on a central role in red lentil production, accounting for a substantial portion of national output. In 2023, Şanlıurfa maintained its leading position in both cultivated area and production, indicating an increasing regional concentration of production.

Although cultivated areas dropped to their lowest level in 2020, they rebounded in 2022 and 2023, reaching approximately 3 million decares, with production climbing to 424,000 tons in 2023, the highest level of the period. However, this increase does not reflect homogeneous development across all provinces. While traditional production centers like Mardin and Diyarbakır experienced fluctuations in both area and yield, provinces such as Siirt, Kahramanmaraş, and Konya recorded notable increases. National average yield fell to 92 kg

da^{-1} in 2021 but recovered to 153 kg da^{-1} in 2023, indicating a trend of recovery. These developments underscore the sensitivity of agricultural production to climate change, irrigation availability, and the use of agricultural inputs.

Balance sheet data for red lentils reflect a structural mismatch between production and consumption. The self-sufficiency ratio dropped to 57% in the 2021/22 period, leading to a substantial need for imports. With the increase in production in 2022/23, the self-sufficiency rate rose to 85.9%, improving the level of supply security for domestic consumption. However, the fact that imports reached as high as 869,000 tons in the same period demonstrates that Türkiye still follows a red lentil policy heavily reliant on external sources. In this context, the sustainability of the foreign trade balance is contingent upon strengthening domestic production and improving supply security. In general, red lentil production remains a critical priority in Türkiye's agricultural planning. However, geographical imbalances in production, disparities in productivity, and vulnerabilities in the trade balance necessitate a restructuring of the current production model. A red lentil policy that is regionally differentiated, prioritizes productivity, supports domestic production, and is resilient to climate risks is of strategic importance for national food security. Additionally, supportive mechanisms such as R&D activities aimed at yield enhancement, farmer education, and the provision of high-quality seed are critical components for the success of this transition. In conclusion, the main challenges facing Türkiye's red lentil production can be summarized as climate change-induced production fluctuations, regional imbalances, low productivity, and dependence on foreign trade. Overcoming these challenges requires climate-adapted production planning, the development of region-based agricultural policies, the expansion of agrarian R&D activities, and the strengthening of producer organizations. Moreover, achieving stability in the production of red lentils, a crop of both agricultural and nutritional importance, is not only an economic necessity but also a strategic imperative for public health and national food security.

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FROM DROUGHT TO TRADE: FIVE YEARS OF CHICKPEA CULTIVATION IN TÜRKIYE

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ABSTRACT
This study investigates the spatiotemporal dynamics of chickpea cultivation in Türkiye over the 2018–2023 period, focusing on cultivated area, production volume, yield variability, and supply-demand equilibrium in the context of climate change. Chickpea, a drought-tolerant legume with high nutritional and agronomic value, plays a crucial role in food security, sustainable agriculture, and public health. However, recent shifts in climate patterns, particularly increasing temperatures and erratic precipitation regimes, have posed significant challenges to agricultural stability in semi-arid regions like Türkiye. Using official agricultural statistics and literature-supported analyses, this study reveals region-specific fluctuations in chickpea production parameters, with provinces such as Ankara, Kayseri, and Çorum exhibiting expansion. In contrast, others, such as Yozgat, Kırşehir, and Adıyaman, demonstrate notable contractions in their cultivation areas. Production data indicate a severe decline in 2021, attributed to one of the driest years in recent decades, followed by a partial recovery in 2022–2023. Yield performance, although improved in provinces like Bartın and Kastamonu, remains below potential in many regions, reflecting the continued need for technological improvement, drought-tolerant cultivars, and localized agronomic strategies. Furthermore, analysis of Türkiye's chickpea balance sheet highlights increased reliance on imports during periods of domestic production shortfall, evidenced by the drop in self-sufficiency to 96% in 2021/22. The study highlights the vulnerability of chickpea cultivation to climatic variability and underscores the need for adaptive agricultural planning. Enhancing regional resilience through climate-smart agrarian practices, targeted extension services, and policy reforms is vital for maintaining production stability and national food security. The findings provide valuable insights for researchers, policymakers, and stakeholders seeking to develop sustainable and climate-resilient pulse production systems in Türkiye.
Keywords: Chickpea, production, yield, cultivation area, agricultural balance, Türkiye

1. INTRODUCTION

Legumes hold a fundamental place in human nutrition due to their high protein content, low fat levels, and rich mineral profiles. Additionally, these crops contribute significantly to the sustainability of agricultural systems by enhancing soil fertility through biological nitrogen fixation (Saxena et al., 2002; Graham & Vance, 2003). One of the most prominent members of this family, chickpea (*Cicer arietinum* L.), is considered a strategic crop in terms of agriculture and food security due to its ability to grow in arid and semi-arid climates, low input requirements, and high nutritional value (FAO, 2020; Gaur et al., 2012). Chickpeas are not only important from an agricultural perspective but also play a crucial role in human health. Rich in high-quality protein, dietary fiber, folate, iron, phosphorus, magnesium, and various phytochemicals, chickpeas contribute to the prevention of cardiovascular diseases, glycemic control, and the maintenance of gut health (Jukanti et al., 2012; Mudryj et al., 2014). Their low glycemic index also makes them a recommended food source for individuals with diabetes.

Thanks to its diverse climatic zones and extensive agricultural lands, Türkiye has the potential to cultivate a wide range of strategic crops, including chickpeas. However, in recent years, the effects of global climate change have had a profound impact on Turkish agriculture. Climate change, through rising temperatures, irregular precipitation patterns, severe droughts, and increased frequency of extreme weather events, has caused water stress, particularly in vulnerable farming regions, leading to significant declines in crop yields (Bozoglu et al., 2019; Kurnaz, 2023). According to the Turkish State Meteorological Service (TSMS, 2025), the year 2021 was recorded as the driest year in the past 20 years and the second driest in the past 41 years. These harsh drought conditions led to yield reductions even in crops considered drought-tolerant, such as chickpeas, revealing the profound impact of climate variability on Turkish agriculture.

Chickpeas are of both historical and current significance for Türkiye's agriculture and economy. Anatolia is recognized as one of the centers of origin and genetic diversity for chickpeas, offering a rich pool of local varieties that serve as valuable genetic resources globally (van der Maesen, 1987). Chickpea production is concentrated primarily in the Central Anatolia, Southeastern Anatolia, and Aegean regions, meeting domestic demand and contributing to export markets. In recent years, with the growing global demand for legumes, demand for chickpeas has also risen, significantly increasing Türkiye's export potential. However, climatic fluctuations and productivity issues in production occasionally undermine the country's competitiveness in foreign trade.

In the context of global climate change, rising temperatures and diminishing water resources have led to yield fluctuations even in chickpea cultivation. In 2021, Türkiye's self-sufficiency ratio in chickpeas dropped to as low as 96% (TURKSTAT, 2025). This suggests that climatic variability must be explicitly considered in the production planning of strategic crops, such as chickpeas. The contraction of cultivation areas, insufficient productivity, and regional imbalances in production hinder Türkiye from fully utilizing its chickpea production potential. Moreover, the limited adoption of modern agricultural practices and the lack of use of climate-resilient varieties make farmers more vulnerable to climate risks.

This study systematically analyzes the transformations in chickpea cultivation in Türkiye during the 2018–2023 period, shedding light on how the agricultural sector is evolving in response to climate change. By examining regional shifts in cultivation areas, fluctuations in production quantities, and differences in yield levels, the study concretely identifies the risks facing agricultural production. Considering the economic and health importance of chickpeas, preserving and enhancing production capacity has become a strategic objective not only economically but also for public health and food security. The study's findings offer valuable

insights for policymakers, agricultural sector stakeholders, and researchers in developing more effective, sustainable, and climate-resilient production strategies.

2. CHICKPEA CULTIVATED AREA IN TÜRKIYE

Chickpea cultivated areas in Türkiye exhibited notable fluctuations between 2018 and 2023. In particular, Ankara province demonstrated remarkable growth in chickpea production during this period. Ankara's chickpea cultivation area increased steadily from 485,479 decares in 2018 to 860,099 decares in 2023, making it the leading province in Türkiye. Similarly, significant expansions in chickpea cultivation were observed in provinces such as Kayseri and Çorum. These provinces steadily expanded their cultivated areas, thereby gaining a larger share of the country's total chickpea area (Table 1). This expansion can be attributed to chickpeas being an attractive option for farmers due to their low water requirements and resilience under harsh environmental conditions (Gaur et al., 2012). In contrast, substantial reductions in cultivated area occurred in provinces such as Kırşehir, Yozgat, and Adıyaman. For instance, in Yozgat, the chickpea cultivation area peaked at 712,618 decares in 2020 but dropped to 559,655 decares by 2023, an approximate 21% decline (Table 1). This decrease can be linked to climate change impacts, declining water availability, and rising production costs (Lobell et al., 2011; Wheeler & von Braun, 2013; Kurnaz, 2023).

At the national level, Türkiye's total chickpea cultivated area decreased from 5,144,159 decares in 2018 to 4,587,718 decares in 2023 (Table 1). This nearly 11% reduction suggests a nationwide contraction in chickpea farming and highlights how climatic and economic factors increasingly pressure legume production. The losses in provinces such as Konya, Kırıkkale, and Adıyaman played a significant role in this overall decline. As Bozoğlu et al. (2019) emphasized, regional contractions support the idea that extreme climatic events, insufficient water supply, and changes in agricultural support policies can have a direct and decisive impact on production patterns.

Conversely, the increases in cultivated areas in provinces such as Ankara, Kayseri, and Çorum helped partially offset the total national decline. The growing interest in chickpea farming in these provinces can be explained by the sustained expectation of economic returns and the perception of chickpeas as a crop that reduces agricultural production risks (Wheeler & von Braun, 2013). Ankara's rise to a leadership position in production highlights that farmers view chickpea farming as both economically viable and strategically significant. The expansion in Kayseri and Çorum is also believed to be supported by favorable climatic conditions, soil structure, and regional market demand (Graham & Vance, 2003).

Table 1. Chickpea Cultivated Areas in Türkiye (da)

Provinces	Years					
	2018	2019	2020	2021	2022	2023
Ankara	485.479	538.774	716.987	766.560	812.884	860.099
Yozgat	418.776	600.985	712.618	657.372	517.059	559.655
Kırşehir	532.518	606.715	535.057	413.735	418.675	373.391
Konya	351.518	336.196	366.721	334.240	294.581	313.646
Kırıkkale	348.001	413.954	394.740	402.651	312.942	273.972
Karaman	232.908	208.377	191.187	222.651	245.356	253.695
Çorum	128.234	189.045	209.297	220.659	231.302	238.526
Kayseri	75.212	93.617	95.138	118.858	137.692	161.867
Adıyaman	274.064	326.157	254.258	153.750	161.997	146.303
Aksaray	83.909	78.509	75.429	87.060	86.700	120.818
Other	2.213.540	1.813.622	1.564.175	1.501.321	1.349.151	1.285.746
Total	5.144.159	5.205.951	5.115.607	4.878.857	4.568.339	4.587.718

(TURKSTAT, 2025)

These observed changes in Türkiye's chickpea cultivated areas indicate increasing regional differentiation in agricultural production and a growing need for flexibility in production strategies. The fact that cultivation areas are expanding in some regions while contracting in others suggests that farmers are adjusting their crop choices based on multi-factorial considerations such as climate, soil fertility, water access, and market conditions. As emphasized in the IPCC (2022) report, agricultural systems are increasingly exposed to the pressures of climate change, necessitating the development of dynamic and adaptive production strategies. Therefore, to ensure the sustainability of chickpea production in Türkiye, it is of great importance to develop agricultural policies that account for regional differences, climate risks, and farmer preferences.

3. CHICKPEA PRODUCTION IN TÜRKIYE

Chickpea production in Türkiye between 2018 and 2023 exhibited regional differences and fluctuations in parallel with changes in cultivated areas. During this period, Ankara province strengthened its leading position in chickpea production. Ankara's chickpea output, which was 57,959 tons in 2018, rose significantly to 93,476 tons in 2020. However, in 2023, production slightly declined to 99,997 tons compared to the previous year, due to factors such as climate variability and rising production costs. The provinces of Yozgat and Kırşehir also experienced notable fluctuations in chickpea production. Yozgat reached its peak in 2019 with 68,614 tons and maintained a similar level of 68,632 tons in 2023. Although Kırşehir saw a sharp drop in production in 2021, it recovered by 2023, reaching 60,725 tons. Meanwhile, provinces such as Çorum, Karaman, and Kayseri demonstrated more consistent growth over the years, contributing positively to Türkiye's total chickpea production (Table 2).

When overall production trends are considered, Türkiye's total chickpea production remained stable at around 630,000 tons between 2018 and 2020 (Table 2). However, in 2021, a severe nationwide drought (TSMS, 2025) led to a sharp decline, resulting in a reduction of total production to 475,000 tons. This drop, driven by drought conditions, led to significant yield losses, especially in regions with higher water demands. This trend is also emphasized by Lobell et al. (2011), who noted that climate change can have severely adverse effects on pulse crop production, particularly in semi-arid regions. In 2022 and 2023, production partially recovered, increasing to approximately 580,000 tons. This recovery is likely associated with improvements in precipitation patterns and the adoption of adaptive agricultural practices by farmers.

Table 2. Chickpea Production in Türkiye (tons)

Provinces	Years					
	2018	2019	2020	2021	2022	2023
Ankara	57.959	67.948	93.476	79.665	111.000	99.997
Yozgat	53.319	68.614	86.417	68.433	67.115	68.632
Kırşehir	65.952	70.813	77.687	44.075	55.934	60.725
Konya	48.845	46.858	50.112	34.029	39.231	46.757
Çorum	18.848	28.701	28.822	24.216	39.233	32.435
Karaman	27.607	26.342	23.382	24.681	31.840	32.391
Kırıkkale	46.697	44.582	29.133	17.693	34.456	26.149
Kayseri	7.592	10.211	9.918	15.218	16.210	22.392
Adıyaman	46.059	47.565	37.791	19.706	22.639	22.035
Aksaray	7.958	7.857	7.327	7.891	8.841	14.256
Other	249.164	210.509	185.935	139.393	153.501	154.231
Total	630.000	630.000	630.000	475.000	580.000	580.000

(TURKSTAT, 2025)

On a regional basis, many provinces in Türkiye experienced production declines during the 2018–2023 period. These losses were most pronounced in areas directly affected by climate

variability, which led to diminished water resources and increased production costs (Challinor et al., 2014; IPCC, 2022). Although pulse crops like chickpeas are relatively resilient to drought and heat stress, the growing frequency of extreme climatic events is undermining this advantage and contributing to production instability. The production decline experienced in 2021 in Türkiye serves as a clear example of the impact of climate change on chickpea cultivation.

The available data indicate a clear need for more balanced production planning to ensure the sustainability of chickpea production in Türkiye. In particular, accurately assessing regional climate risks and promoting the adoption of modern agricultural techniques, improved irrigation systems, and drought-tolerant chickpea varieties are of great importance (Ceyhan et al., 2012; Gaur et al., 2012; Kahraman et al., 2016). Additionally, the development of support programs that enhance farmers' capacity to adapt to climate change will be a key strategy for mitigating production fluctuations and strengthening supply security in Türkiye's chickpea sector.

4. CHICKPEA YIELD IN TÜRKIYE

Between 2018 and 2023, chickpea yield in Türkiye showed fluctuating trends at the provincial level, with national average yield levels generally remaining low. Considering that Türkiye's average yield during these years ranged between 99–127 kg da^{-1}, it is evident that chickpea productivity remains below its potential in many regions (Table 3). This situation reflects the limiting effects of both climatic stressors, such as drought, and the limited use of advanced production technologies (Lobell & Field, 2007; Ceyhan et al., 2012; Kahraman et al., 2016; IPCC, 2022). However, some provinces have demonstrated noteworthy improvements in productivity contrary to this general trend. For instance, in Bartın, the grain yield increased from 196 kg da^{-1} in 2018 to 250 kg da^{-1} in 2023. Similarly, in Kastamonu, yield rose from 100 kg da^{-1} to 250 kg da^{-1} over the same period. These increases suggest that input use has become more efficient in these areas, modern agricultural techniques are being adopted, or climatic conditions have been relatively more favorable.

Table 3. Chickpea Yield in Türkiye (kg da^{-1}**)**

Provinces	Years					
	2018	2019	2020	2021	2022	2023
Bartın	196	211	206	219	219	250
Kastamonu	100	111	154	205	217	250
Hatay	163	181	178	234	215	214
Edirne	143	137	135	177	216	212
Bitlis	115	116	132	102	154	176
Karabük	82	93	99	102	162	172
Batman	146	149	169	68	161	171
Bingöl	142	151	145	120	143	168
Diyarbakır	164	156	172	99	148	167
Kırşehir	124	117	145	107	134	163
Mean of Türkiye	123	122	123	99	127	126

(TURKSTAT, 2025)

Comparable yield improvements have also been recorded in provinces with distinct agroecological characteristics, such as Edirne and Bitlis. In Edirne, chickpea yield increased from 143 kg da^{-1} in 2018 to 212 kg da^{-1} in 2023. In Bitlis, yield rose from 115 kg da^{-1} in 2018 to 176 kg da^{-1} in 2023 (Table 3). These data show that improving agricultural productivity across different geographical regions is feasible, but such success depends on strategies and practices tailored to local production conditions. Yield improvement is not only a function of genetic potential but also relies on the integration of factors such as soil management,

optimized sowing time, and water management (Gaur et al., 2012; Singh et al., 2014; Kahraman et al., 2016).

The development of drought-tolerant chickpea varieties plays a critical role in ensuring yield stability. According to FAO (2020), for legume crops that offer high yield with minimal input, genetic improvement, appropriate mechanization, and farmer training are all essential components. In the case of Türkiye, the high yield values recorded in provinces such as Bartın and Kastamonu indicate that environmental conditions have been optimized and agricultural knowledge has been successfully integrated into production systems in these regions.

Chickpea productivity in Türkiye continues to vary significantly by region, and the fact that many areas remain below the national average highlights the need to expand the use of modern agricultural practices and strengthen climate-adapted production strategies. Achieving yield increases requires not only climatic advantages but also knowledge-based production decisions, sustainable input use, and effective utilization of agricultural support mechanisms. In this context, making more efficient use of regional yield potential in chickpea production is of strategic importance for both domestic consumption and export capacity.

5. CHICKPEA BALANCE STATUS IN TÜRKIYE

An evaluation of Türkiye's chickpea balance status during the 2018/19–2022/23 period reveals that production volumes remained relatively stable over the first three years. Still, significant fluctuations occurred later due to the decisive impact of climatic conditions. In the 2018/19 and 2020/21 production seasons, annual total production remained steady at approximately 630,000 tons (Table 4). This stability can largely be attributed to the continuation of favorable weather conditions, the preservation of cultivation areas, and the absence of significant shifts in production patterns. In the literature, such stable production periods are typically characterized as years with minimal climatic variability, sufficient rainfall to meet crop water needs, and consistent producer behavior (Lobell & Gourdji, 2012; Wheeler & von Braun, 2013).

However, the severe drought experienced during the 2021/22 production season marked a critical turning point for chickpea production. The widespread drought across Türkiye led to both a contraction in sown areas and a decline in yield levels, resulting in a 24.6% decrease in production compared to the previous year, down to 475,000 tons (Table 4). As emphasized in the IPCC (2022) report, such climate-induced extreme weather events have sudden and severe impacts on agricultural production, particularly in semi-arid regions. In the case of Türkiye, 2021 was recorded by the Turkish State Meteorological Service (TSMS, 2025) as the driest year in the past two decades, and this led to substantial production losses even in relatively drought-tolerant crops like chickpeas.

In the 2022/23 production season, a modest recovery in chickpea output was observed, with total production rising to approximately 580,000 tons (Table 4). This increase is associated with the re-expansion of cultivated areas and compensatory actions taken by farmers in response to the previous year's production losses. Such compensatory production behavior is considered an adaptive response to climate shocks and is critical for the development of sustainable production strategies (Challinor et al., 2014; FAO, 2020).

Post-harvest losses during the production process remained relatively constant over the years, accounting for about 1.3% of total production annually (Table 4). This proportional consistency suggests that such losses are primarily driven by structural issues (e.g., insufficient storage infrastructure, transportation-related losses, combine harvester inefficiencies) and tend to be independent of short-term climatic variations (Parfitt et al., 2010). Consequently, the amount of available production has followed the same trend as total production, reaching its lowest point in 2021/22. These findings highlight the high sensitivity of chickpea production

in Türkiye to climatic conditions and underscore the need to restructure production planning to account for climate-related risks proactively.

Table 4. Chickpea Balance Sheet in Türkiye

	Years				
	2018/19	2019/20	2020/21	2021/22	2022/23
Production (tons)	630.000	630.000	630.000	475.000	580.000
Post-Harvest Losses (tons)	8.190	8.190	8.190	6.175	7.540
Supply = Utilization (tons)	698.949	642.340	692.965	618.595	789.017
Available Production (tons)	621.810	621.810	621.810	468.825	572.460
Imports (tons)	77.139	20.530	71.155	149.770	216.557
Domestic Utilization (tons)	545.288	487.562	508.537	488.227	486.109
Human Consumption (tons)	464.782	407.696	429.321	407.717	410.000
Seed Use (tons)	66.874	67.677	66.503	68.304	63.957
Losses (tons)	13.632	121.89	12.713	12.206	12.153
Exports (tons)	224.018	142.888	268.468	193.526	230.806
Stock (tons)	-70.357	11.890	-84.040	-63.158	72.102
Per Capita Consumption (kg)	5.7	4.9	5.1	4.8	4.8
Self-Sufficiency Ratio (%)	114.0	127.5	122.3	96.0	117.8

(TURKSTAT, 2025)

Türkiye's chickpea supply-demand balance during the 2018/19–2022/23 period exhibited notable fluctuations not only in production levels but also in imports, exports, domestic consumption, and stock dynamics. Especially in the 2021/22 season, when production declined significantly, there was a sharp increase in external trade activity and a marked drop in the self-sufficiency ratio. In this context, chickpea imports, which were just 20,530 tons in 2019/20, rose dramatically to approximately 150,000 tons in 2021/22 and peaked at 216,557 tons in 2022/23 (Table 4). These figures reveal Türkiye's growing dependence on foreign supply to buffer domestic production fluctuations and maintain food security. As noted by FAO (2020) and Wheeler and von Braun (2013), countries tend to increase their reliance on imports during periods of heightened climate risk. This approach introduces structural vulnerabilities into national agricultural policy frameworks.

Domestic utilization remained relatively stable throughout the period, generally ranging between 480,000 and 550,000 tons. Most of this volume was allocated to human consumption, which was recorded at 410,000 tons in the 2022/23 season. The remainder of the available supply was used for seed purposes (approximately 64,000 tons) and technical losses, such as post-harvest shrinkage (Table 4). According to Parfitt et al. (2010), post-harvest losses in many agricultural products, especially in developing countries, tend to increase due to insufficient storage, transportation, and processing infrastructure. This directly limits the usable production potential. In the case of chickpeas in Türkiye, annual post-harvest losses have remained stable at around 12,000–13,000 tons, suggesting that these are chronic, structural losses embedded in the supply chain.

Export volumes, on the other hand, showed more variability. In 2020/21, Türkiye achieved a high export level of 268,468 tons. However, in the following years, export volumes declined—likely due to prioritization of domestic market needs in response to reduced production. Notably, in the 2021/22 season, domestic production fell short of meeting demand, which led to export restrictions and a boost in imports (Table 4). As emphasized by FAO (2020), in countries experiencing climate variability and supply shortages, the direction of trade flows is shaped by production shocks, making external trade increasingly fragile.

Per capita chickpea consumption also showed a declining trend during this period. While it was 5.7 kg in 2018/19, it dropped to 4.8 kg by 2022/23 (Table 4). This decrease can be attributed not only to falling production levels but also to changes in consumer behavior,

rising prices, and increased competition among legumes. As highlighted by Mudryj et al. (2014), the sustainability of consumption is not solely tied to availability, but also to consumer accessibility and perception of the product.

The self-sufficiency ratio stands out as one of the most critical indicators of this period. Türkiye's capacity to meet domestic chickpea demand with its production stood at 114% in 2018/19 and 122.3% in 2020/21. However, it dropped to 96% in 2021/22, signaling the loss of national self-sufficiency in chickpea production (Table 4). This development aligns with the IPCC (2022) report, which stresses that climate-induced production vulnerabilities can compromise not only supply security but also overall food security. Nevertheless, by 2022/23, thanks to both a partial recovery in production and substantial import volumes, the self-sufficiency ratio rebounded to 117.8% (Table 4). This suggests that while foreign trade can temporarily offset supply deficits, it does not resolve the underlying structural issues in domestic production and thus serves only as a short-term buffer from a sustainability perspective (Lobell et al., 2011).

6. CONCLUSION AND EVALUATION

This study evaluated the development of chickpea cultivation in Türkiye between 2018 and 2023 in terms of sown area, production volume, grain yield, and supply-demand balance, and presented the impacts of climate change on agricultural production using concrete data. The findings indicate that chickpea production in Türkiye is sensitive to both climatic and structural factors, and this fragility has direct implications for production planning, trade balance, and food security.

In terms of sown area, while a general trend of contraction is observed, some provinces, such as Ankara, Kayseri, and Çorum, have shown consistent growth. This highlights the increasing regional differentiation in agricultural production and demonstrates that climate-agriculture interactions directly influence farmers' preferences. During the same period, production volumes followed a similar trajectory. The severe drought in 2021 led to both a reduction in cultivated area and a decline in yield, resulting in an approximate 25% drop in total production. The recovery observed in 2022 and 2023 was made possible by favorable climatic conditions and compensatory production behavior, demonstrating that producers possess adaptive capacity in the face of environmental shocks.

From a productivity perspective, Türkiye's national average remains low compared to many other countries. However, significant yield increases recorded in provinces such as Bartın, Kastamonu, Edirne, and Bitlis reveal the positive impact of local-level adoption of modern agricultural techniques and suitable varieties. These findings emphasize that yield improvements should not rely solely on genetic potential but must also be supported by integrated approaches such as water management, soil improvement, and farmer training. Especially in a period marked by increasing climate variability, the development and widespread adoption of drought-tolerant chickpea varieties emerge as a strategic necessity for yield stability.

Supply-demand balance analyses show that fluctuations in Türkiye's chickpea production directly affect import and export volumes. In years with sufficient production, exports increased, while in years like 2021/22, when production was inadequate, imports rose, resulting in a decline in the self-sufficiency ratio. The drop of the self-sufficiency ratio to 96% in the 2021/22 season highlighted the risk of Türkiye becoming dependent on external supply. However, in the 2022/23 season, the self-sufficiency ratio rose to 117.8%, thanks to both increased imports and a recovery in production. Nevertheless, it must be noted that such trade interventions serve only as short-term solutions to bridge supply gaps, rather than addressing the underlying structural issues in production. A sustainable chickpea production model should

not rely on foreign trade but should be built around climate-resilient infrastructure and regionally targeted planning.

In conclusion, to enhance the sustainability of chickpea production in Türkiye, it is essential to develop climate-resilient agricultural policies, promote the widespread use of modern production techniques, establish region-specific production strategies, and improve input efficiency. In addition, raising farmers' knowledge levels, aligning support programs with climate risks, and integrating the food security perspective into production planning are all critically important to meet domestic demand and maintain competitiveness in international markets. In this regard, agricultural policies should not only aim for short-term productivity gains but also be grounded in long-term climate adaptation and socioeconomic sustainability principles, one of the key approaches to reinforcing Türkiye's strategic advantage in pulse production.

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ON-SITE DETERMINATION OF CONCRETE STRENGTH BY DIRECT AND INDIRECT METHODS

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ABSTRACT

In this paper 'concrete strength' means 'compressive strength of concrete'. The direct way of determining the concrete strength of an existing reinforced concrete (RC) building is done by taking cylindrical cores at randomly chosen points of columns and slabs and crushing them in a certified concrete compression machine after properly capping each core sample at both ends. This procedure will reveal a clear-cut result about the on-site concrete strength. Yet, this is a labor-intensive method having a few disadvantages which are summarized in the ensuing sections. At least 8 cores should be taken from a RC building in order to evaluate its overall concrete strength. For high-story RC buildings more number of cores will be needed. There are relevant standards of many countries for this direct method. A common and widely known indirect method for estimation of concrete strength of a RC member is by measuring its surface hardness with the help of a standard instrument known as Schmidt Hammer, which is a low cost and easy-to-use device. The strength given by the chart attached to the instrument against the median of 11 hardness measurements, also called rebound values, taken by applying the Schmidt Hammer on an area of about 20×20 cm dimensions yields an estimate at that point. According to its Users' Manual the Schmidt Hammer is expected to give reliable values for the strength of concrete whose age is within 4 and 8 weeks after casting. It underestimates for too young concrete due to incomplete hydration of cement and overestimates for old concrete due to hardening of the surface by calcium-carbonite formation. Another indirect method for estimating the concrete strength of a RC member is by measuring the travel time of ultrasonic pulse (sound wave) passing through it with the help of a standard instrument known as Pundit. This device has an affordable cost and it is fairly easy to use. Over decades of research, it has been determined that there is a correlation between the ultrasonic pulse velocity and the modulus of elasticity and the strength of concrete. An ordinary grease will be plastered on the corresponding faces of the RC member where the two transducers are pushed against. The distance between the transducers in mm divided by the pulse travel time across them in microseconds yields the ultrasonic pulse velocity in km/s. The concrete strength can be estimated against the pulse velocity from the chart given in the Users' Manual of the instrument. Quite a few studies have been done in Kayseri and in various cities of Türkiye by a group of technicians whose lead investigator was the author of this paper. The summary of one of them will be presented here without identifying the name and whereabouts of that RC building. A conclusion of such studies is that the Schmidt Hammer readings usually overestimates the concrete strength if its own chart is used for RC buildings which are one year and longer old. Another conclusion is that for RC buildings statistically meaningful regressions can be obtained between the core strength and the ultrasonic pulse velocity. Hence, for a RC building aged a few years, estimation of concrete strength of its load-carrying members other than those at which cores are taken using the regression equation relating the concrete strength to the ultrasonic pulse velocity obtained for this building should yield reliable results.

Keywords: Compressive strength of concrete, concrete strength, determination of concrete strength by direct and indirect methods, Schmidt Hammer, surface hardness of concrete, ultrasonic pulse velocity of concrete, Pundit.

INTRODUCTION

Türkiye is an earthquake-prone country which has experienced many severe and moderate earthquakes in the last centuries. The last one with a Richter magnitude of 7.6 occurred on February 6th of 2023 over a vast area of the southeastern part whose epicenter was close to the city of Kahramanmaraş, and it caused collapses of thousands of buildings in the provinces of Kahramanmaraş, Hatay, Adıyaman, Malatya, Adana, Gaziantep resulting in a heavy death toll of more than 50,000 inhabitants. According to various technical reports prepared in the aftermath of this devastating earthquake, low concrete quality was pointed out as one of the major causes of the collapses and heavy structural damages of so many reinforced concrete (RC) buildings. In this paper 'concrete strength' means 'compressive strength of concrete'. Determination of concrete strength of any RC building whether it is subjected to earthquakes or not has been an important task for engineers, especially in recent decades.

Taking sufficient number of 15 cm cubical or 15×30 cm cylindrical specimens in standard molds during casting of fresh concrete at every story of a RC building and determining the 28-day strengths of these specimens by crushing them one by one in a certified concrete compression machine after having been soaked in a curing tank of 20 ± 2 °C temperature is a legal obligation in Türkiye (e.g. TSE 2000) and similarly in other countries of the world. Even if the strength measured on these samples is satisfactory, the actual strength of concrete in the load-carrying members may be lower because of improper placing of fresh concrete in the forms of the load-carrying structure of the building and especially improper curing of the hardened concrete within the few days after casting. Therefore, determining the strength of concrete existing in the structural skeleton of a RC building has always been a vital issue.

The clear-cut and direct way of determining the on-site concrete strength is taking cylindrical cores at randomly chosen points of columns and slabs by skipping the embedded reinforcement bars and crushing them in a certified concrete compression machine after having been properly capped at both ends. In Türkiye, the details of this method are explained in relevant and legally-binding publications (Anonymous 2021, TSE 2019b, TSE 2019c). Yet, this laborious procedure has a few disadvantages. First, taking a single core takes about 30 minutes at least. Second, it causes a structural damage in the form of a hole, and therefore, the number of cores must be kept to a minimum. Third, this procedure requires a set of hardware consisting of a core-taking machine, a drilling machine for opening nests for steel dowels, a mobile water tank supplying lubrication water to the core barrel, a special bolt and screw unit for fixing the machine on the RC column or slab, and various tools like wrenches, pliers, and a hammer.

In order to enhance the assessment of concrete strength of many more load-carrying members, like columns, shear walls, beams, and slabs, a few different methods for indirectly estimating the concrete strength are available and their procedures are explained in relevant standards (e.g. ACI 1998, TSE 2021a, TSE 2021b). The most common and widely known method is estimation of strength by measuring the surface hardness of the concrete member with the help of a standard instrument known as Schmidt Hammer (TSE 2021a), which is a low-cost and easy-to-use device. Taking 11 hardness measurements by applying the Schmidt Hammer 11 times on 11 points within an area of about a 20×20 cm dimensions and reading the corresponding strength against the median of 11 readings from the chart given on the instrument yields an estimate at that point. However, the Schmidt Hammer must be applied on concrete whose age is within 4 and 8 weeks after casting. It underestimates for too young

concrete due to incomplete hydration of cement and overestimates for old concrete due to hardening of the surface by calcium-carbonite formation.

Another indirect method for estimation of concrete strength is done by measuring the travel time of ultrasonic sound through a RC column, a shear wall, or a beam (TSE 2021b). Over decades of research, it has been determined that there is a correlation between the ultrasonic pulse velocity and the modulus of elasticity and the strength of concrete (e.g. Lin et al 2007, TSE 2021b, Said and Ali 2021). The instrument to measure the travel time in microseconds from one side to the other side of a RC member is light and easy to handle. An ordinary grease or petroleum jelly will be plastered on the surfaces of the two faces of the column across each other where the two transducers are pushed against. The distance between the transducers in mm divided by the pulse travel time across them in microseconds yields the ultrasonic pulse velocity in km/s. One can estimate the concrete strength against the pulse velocity using the chart suggested in the Users' Manual of the instrument.

There is another indirect method known as 'pull-out testing' (TSE 2019b). This method is not as common as the other two mentioned above, and we will not cover it here.

At the point where the core is extracted, both the Schmidt Hammer surface hardness and the ultrasonic pulse travel time measurements will be taken prior to cutting out of the core. A regression analysis will be done relating the core strength to the surface hardness at those points where the cores are taken. If a statistically meaningful regression equation is obtained, then the strengths of many more load-carrying members will be estimated using this equation after having taken Schmidt Hammer readings on them. Similarly, another regression analysis will be done relating the core strength to the ultrasonic pulse velocity at those points where the cores are taken. If a statistically meaningful regression equation is obtained, then the strengths of many more load-carrying members will be estimated using this equation after having measured ultrasonic pulse travel times on them. Hence, a more comprehensive evaluation of concrete strength all over the building will be made.

The objective here is to briefly explain these three methods and to present the summary of one of many studies which have been done in various cities of Türkiye whose lead investigator was the author of this paper without identifying the name and whereabouts of that RC building.

RESEARCH AND FINDINGS

We have carried out the direct method of taking concrete cores and the indirect methods of Schmidt Hammer applications and ultrasonic pulse measurements for assessing the on-site concrete strength of many RC buildings in various cities of Türkiye in recent decades. We will give the results of one of these here in this paper.

The direct method of taking cylindrical concrete cores, straightening both ends of a core sample by a rock-cutting saw, capping both ends by sulfur-graphite powder compound, crushing each sample in a certified concrete compression machine and evaluating the ultimate strengths of so many samples according to the relevant Turkish Standards are explained in TS EN 12390−3 (TSE 2019a), TS EN 13791 (TSE 2019b) and TS EN 12504-1 (TSE 2019c). The height of each core sample should be equal to its diameter as the diameter of cores should be 75 mm. 50 mm cores also are allowed in case the embedded reinforcement bars are too close to each other. The details of the standard procedures will not be rewritten here. Figure 1 shows determination of

positions of the reinforcement bars with the help of the instrument known as Ferro Master. Figure 2 shows taking of a core from a column of a RC building. Figure 3 shows the group of all the cores taken from a RC building. Figure 4 shows the straightening procedure of both ends of a core sample in a rock-cutting saw after it is transported to the Materials Laboratory. Figure 5 shows the capping of one such sample. Figure 6 shows all the capped core samples ready to be crushed. Figure 7 shows a core sample being crushed in a certified concrete compression machine. Next to crushing all of the samples, a table of results is prepared indicating the ultimate loads and ultimate strengths of all of the samples. At the bottom of this table, the arithmetic average and the standard deviation of the strengths of the crushed samples are given.

Figure 1. Determining the positions of the longitudinal and the lateral reinforcement steel bars inside a column with the help of a Ferro Master instrument.

Figure 2. Extracting a core from a column.

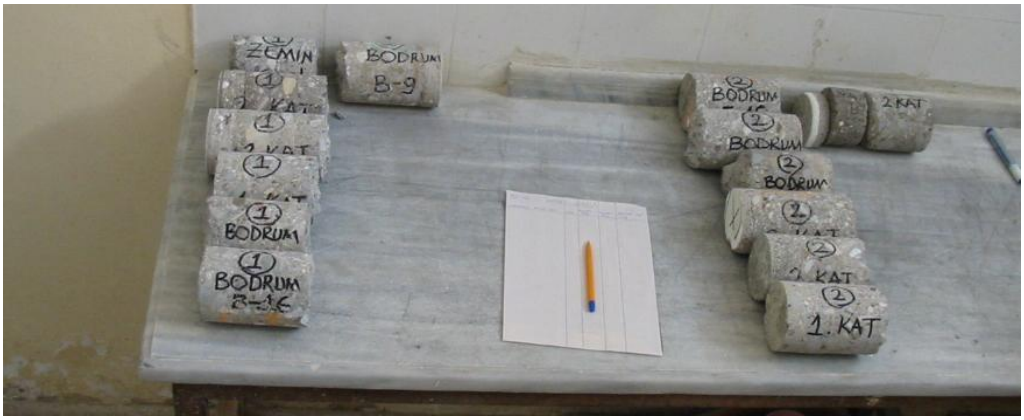

Figure 3. Extracted concrete cores before end preparations.

Figure 4. Straightening of one end of a core in the rock-cutting saw.

Figure 5. Capping of a straightened core sample with sulfur-graphite powder compound.

Figure 6. Capped core samples ready to be crushed in the concrete compression machine.

Figure 7. A core sample being crushed in a certified concrete compression machine (The certification reports are attached to the left side and the green certification stickers are bonded to the front side of the machine, which are issued after control tests done annually by the Turkish Standards Institute).

The details of the standard procedures of the indirect method of surface hardness measurements by a Schmidt Hammer are explained in TS EN 12504-2 (TSE 2021a), and they will not be repeated here. The plaster cover over the surface of the load-carrying member must be removed beforehand and the Schmidt Hammer must be applied on the concrete surface. Figure 8 shows the instant of applying the Schmidt Hammer on a load-carrying member. 11 hardness measurements (rebound values) are taken on 11 points within a small area. A table is prepared indicating on its first column the identification of the tested member proceeded by 11 readings and their median value. And, on the last column, the concrete strength against the median value given by the chart on the instrument is presented. At the bottom of this table, the arithmetic average and the standard deviation of the estimated strengths of the members based on the chart of the used Schmidt Hammer are given.

Figure 8. Applying the Schmidt Hammer to the surface of a column.

The details of the standard procedures of the indirect method of ultrasonic pulse travel time measurements by a Pundit instrument are explained in TS EN 12504-4 (TSE 2021b), and they will not be repeated here. The plaster cover over the surface of the load-carrying member must be removed beforehand and the transmitter and receiver transducers of the Pundit instrument must be applied on concrete surface after having spread grease. Figure 9 shows the instant of one such measurement. A table is prepared presenting the measured quantities, which are the distance between the transducers in mm, the travel time of the ultrasonic pulse in microseconds, and the estimated concrete strength as given by the generalized chart given in the Users' Manual of the Pundit instrument.

Figure 9. Measuring the ultrasonic pulse travel time from one side to the other side of a column with the help of a Pundit instrument.

Figure 10 shows the regression line relating the core strength in N/mm^2 against the median of 11 Schmidt Hammer readings at the building presented here as an example. Figure 11 shows the regression line relating the core strength in N/mm^2 against the ultrasonic pulse velocity in km/s at the building presented here as an example. As can be seen by comparing these two figures, the regression between the core strength and the ultrasonic pulse velocity is more meaningful than the former because the noises of the measured points around the regression line are smaller.

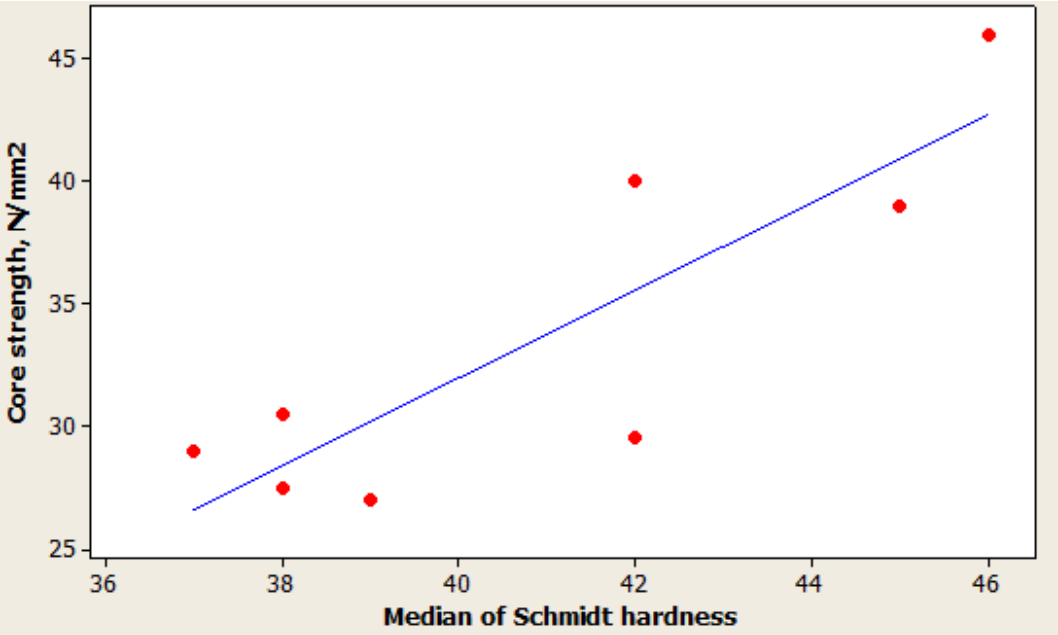

Figure 10. Plot of measured core strengths against Schmidt Hammer hardness readings and the regression line at the RC building presented as a case study.

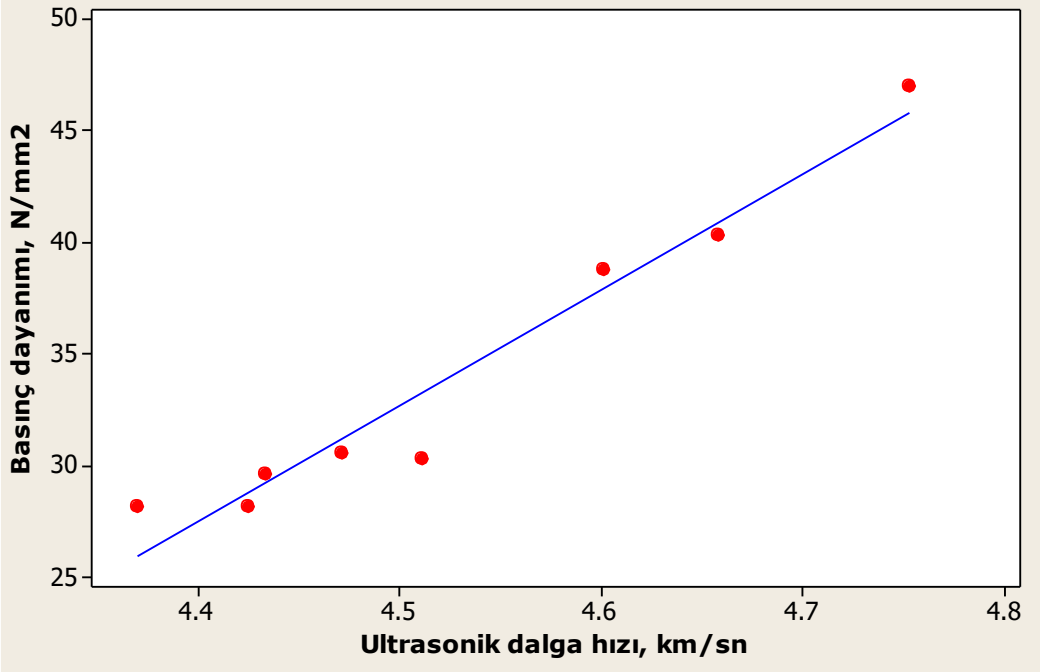

Figure 11. Plot of measured core strengths against ultrasonic pulse velocities and the regression line at the RC building presented as a case study.

The results of the three tests all indicated that the concrete class of the investigated building was C30 meaning that the characteristic strength of concrete of this RC building was 30 N/mm^2. The characteristic strength statistically means that with a 95 % probability the strength of concrete in this building is greater than or equal to 30 N/mm^2 which also means that there is a 5 % probability that the strength of concrete in this building is smaller than 30 N/mm^2.

CONCLUSION

The direct method and two indirect methods for assessing the compressive strength of concrete of an existing RC building are summarized here and their applications on a RC building are presented as a case study. It is believed that for a RC building aged a few years, estimation of concrete compressive strengths of its load-carrying members other than those at which cores are taken using the regression equation relating the core strength against the ultrasonic pulse velocity obtained for the same building should yield reliable results.

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TSE (2019c) TS EN 12504−1 Testing concrete in structures - Part 1: Cored specimens - Taking, examining and testing in compression. Turkish Standards Institute, Ankara, Türkiye.

TSE (2021a) TS EN 12504−2 Testing concrete in structures - Part 2: Non-destructive testing - Determination of rebound number. Turkish Standards Institute, Ankara, Türkiye.

TSE (2021b) TS EN 12504−4 Testing concrete in structures - Part 4: Determination of ultrasonic pulse velocity. Turkish Standards Institute, Ankara, Türkiye.

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ÖZET

Çevre, organizmaların birbirleriyle etkileşimde bulunduğu yaşam alanıdır. İnsanların çevre üzerindeki etkisi arttıkça, doğal *Atherina boyeri* (Risso, 1810), Türkiye'de yaygın olarak "gümüş balığı" olarak bilinen bir tür olup, Akdeniz bölgesinin hem tuzlu hem de acı su kaynaklarında yaygın olarak bulunmaktadır. Bu tür, genellikle sığ kıyı sularında, lagünlerde ve nehir ağızlarında yaşamaktadır. *Atherina boyeri*, hızlı üreme kapasitesi ve çevresel koşullara yüksek adaptasyon yeteneği ile tanınmakta, bu özellikleri sayesinde sucul ekosistemlerde önemli bir yer tutmaktadır. Ayrıca bu balık türü, hem yırtıcı balıklar hem de kuşlar için önemli bir besin kaynağı olarak ekosistem içi besin ilişkilerinde kritik bir rol üstlenmektedir. Bu çalışmada, 2024–2025 av sezonunda farklı bölgelerden toplanan *Atherina boyeri* bireylerinin toplam boy (TL), standart boy (SL) ve çatal boy (FL) ölçümleri 0,1 mm hassasiyetli dijital kumpas ile, ağırlık (W) ölçümleri ise 0,01 g hassasiyetli terazi ile kaydedilmiştir. Her bireyin cinsiyeti de belirlenmiştir. Elde edilen tüm boy verileri (TL, SL, FL) ve cinsiyet bilgileri, Lojistik Regresyon, Destek Vektör Makineleri (SVM), Çok Katmanlı Algılayıcı Sinir Ağı (MLPNN) ve Radyal Tabanlı Fonksiyon Sinir Ağı (RBFNN) gibi çeşitli makine öğrenmesi sınıflandırıcıları kullanılarak değerlendirilmiştir. Kullanılan sınıflandırıcıların performansı, çok sınıflı karışıklık matrisi (confusion matrix, CM) aracılığıyla ortaya konmuştur. Çalışmada değerlendirilen makine öğrenmesi modellerinin performansları karşılaştırılmış ve analiz edilmiştir. Elde edilen sonuçlar, karmaşık veri setlerinde dahi yüksek doğruluk oranlarıyla başarılı sınıflandırma potansiyeline sahip yapay zeka modellerinin, geleneksel yöntemlerle tutarlı sonuçlar verdiğini göstermektedir. Özellikle popülasyon dinamiklerinin izlenmesi, türlerin büyüme özelliklerinin anlaşılması ve ekosistem sağlığının değerlendirilmesi gibi alanlarda makine öğrenmesi yöntemlerinin kullanımı, gelecekteki çalışmalara önemli bir yol haritası sunmaktadır. Bu bulgular, yapay zekâ temelli yaklaşımların sucul ekosistemlerde biyolojik çeşitlilik ve popülasyon çalışmalarında giderek daha fazla benimseneceğini göstermektedir.

Anahtar Kelimeler: Makine öğrenmesi, *Atherina boyeri*, yapay zeka

Teşekkür

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MACHINE LEARNING APPROACHES IN CLASSIFYING AND ANALYZING ATHERINA BOYERI

ABSTRACT

Atherina boyeri, commonly known as the “silver fish” in Turkish, is a species widely found in both saline and brackish water sources of the Mediterranean region. This species typically lives in shallow coastal waters, lagoons, and river mouths. *Atherina boyeri* is known for its rapid reproductive ability and adaptability, making it an important species in aquatic ecosystems. Additionally, this fish plays a critical role in the food chain of aquatic ecosystems and serves as a valuable food source for both predatory fish and birds. In this project, individuals of *Atherina boyeri* (Risso, 1810) collected from various locations during the 2024-2025 fishing season were measured for total length (TL), standard length (SL), and fork length (FL) using a digital caliper with a precision of 0.1 mm, and their weight (W) was recorded with a scale accurate to 0.01 g. The sex of each specimen was determined. All length data (total length, standard length, and fork length) and sex information will be evaluated using machine learning classifiers, including Logistic Regression, Support Vector Machine (SVM), Multilayer Perceptron Neural Network (MLPNN), and Radial Basis Function Neural Networks (RBFNN). The performance of the classifiers used will be presented through a multi-class confusion matrix (CM). The performance of the machine learning models considered in the study was compared and evaluated. In this study, the results obtained using artificial intelligence models showed high classification potential with high accuracy rates, even with more complex datasets, while being consistent with traditional methods. Particularly in areas such as monitoring population dynamics, understanding species growth patterns, and evaluating ecosystem health, the use of machine learning methods offers an important roadmap for future studies. These findings indicate that AI-based approaches will increasingly be adopted in biological diversity and population studies in aquatic ecosystems.

Keyword: Machine learning, *Atherina boyeri*, artificial intelligence

Acknowledgments

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1. GİRİŞ

Dünya genelinde iç su kaynaklarının korunması ve sürdürülebilir kullanımı, giderek artan nüfus, iklim değişikliği ve su kirliliği gibi çevresel baskılar nedeniyle büyük önem kazanmıştır. Türkiye, bu bağlamda iç su kaynakları açısından oldukça zengin bir ülke olup, sahip olduğu göl, gölet ve nehirlerle hem ekolojik hem de ekonomik değer taşımaktadır. Ülkemizde yaklaşık 200 doğal göl, 555 baraj gölü ve 664 gölet bulunmakta olup, bu kaynaklar farklı bölgelere yayılmış durumdadır. Ayrıca, 33 nehir sisteminin toplam uzunluğu yaklaşık 178.000 kilometreyi bulmaktadır (DSİ, 2016; Geldiay ve Balık, 2009). Bu sucul sistemler, çeşitli balık türlerine yaşam alanı sunmakta ve yüksek düzeyde biyolojik çeşitliliğe ev sahipliği yapmaktadır.

Uluslararası Doğayı Koruma Birliği'nin (IUCN) 2004 yılı verilerine göre, Türkiye'nin tatlısu balık faunası Avrupa kıtasındaki en zengin faunalardan biri olmasına rağmen, birçok endemik tür habitat kaybı, aşırı avcılık ve kirlilik gibi tehditlerle karşı karşıyadır (Smith ve Darwall, 2006). Bu durum, balık popülasyonlarının izlenmesini ve türlerin biyolojik özelliklerinin ayrıntılı şekilde incelenmesini zorunlu kılmaktadır.

Bu çalışmada ele alınan *Atherina boyeri* (Risso, 1810), yaygın olarak "gümüş balığı" adıyla bilinen, Türkiye'nin özellikle Akdeniz ve Ege kıyılarındaki lagün, haliç ve sığ kıyı sularında bol miktarda bulunan bir türdür (Çetinkaya ve ark., 2010). Bu tür, yüksek toleranslı yapısı sayesinde hem acı hem de tatlı sularda yaşayabilmekte ve çeşitli çevresel koşullara kolayca uyum sağlayabilmektedir (Öztekin ve ark., 2019). Ekosistemlerdeki rolü oldukça kritiktir; çünkü hem yırtıcı balık türleri hem de su kuşları için besin kaynağı olması nedeniyle trofik düzeyde önemli bir basamaktadır (Bulut & Kubilay, 2018).

Son yıllarda, balıkların biyometrik ve morfolojik verilerinin analizinde, geleneksel istatistiksel yöntemlerin yanı sıra, daha hızlı ve isabetli sonuçlar sunabilen makine öğrenmesi (ML) algoritmaları da yaygın olarak kullanılmaya başlanmıştır (Benzer ve ark., 2022). Bu teknikler, büyük ve karmaşık veri kümeleri üzerinde modelleme yapılmasına imkân tanırken, özellikle tür tespiti, cinsiyet ayrımı ve yaş tahmini gibi konularda da önemli avantajlar sunmaktadır.

Bu çalışmanın temel amacı, *Atherina boyeri* türünün çeşitli morfometrik ölçümlerini ve cinsiyet bilgilerini kullanarak, farklı makine öğrenmesi algoritmalarının sınıflandırma performanslarını karşılaştırmaktır. Böylece, türün popülasyon dinamiklerinin daha iyi anlaşılması ve sürdürülebilir yönetim stratejilerinin geliştirilmesi için bilimsel bir temel oluşturulması hedeflenmektedir.

2. MATERYAL VE METOD

2.1. Örnekleme Süreci ve Laboratuvar Koşulları

Bu çalışma kapsamında, 2024-2025 av sezonunda Türkiye'nin farklı bölgelerinden *Atherina boyeri* (gümüş balığı) örnekleri rastgele örnekleme yöntemi ile toplanmıştır. Toplanan bireyler, canlılık durumları korunarak laboratuvara taşınmış ve analizler öncesinde standart prosedürlere uygun şekilde hazırlanmıştır. Bu hazırlık sürecinde örneklerin ölçümleri alınmadan önce herhangi bir deformasyonun önüne geçmek amacıyla dikkatli taşıma ve muhafaza koşulları sağlanmıştır (Benzer & Benzer, 2017).

2.2. Morfometrik Ölçümler ve Cinsiyet Tespiti

Laboratuvar ortamında her bir bireyin morfometrik özellikleri titizlikle kaydedilmiştir. Toplam boy (Total Length, TL), standart boy (Standard Length, SL) ve çatal boy (Fork Length, FL) ölçümleri 0,1 mm hassasiyetindeki dijital kumpas kullanılarak alınmıştır. Bireylerin ağırlık (Weight, W) ölçümleri ise 0,01 g duyarlılığa sahip dijital terazi ile gerçekleştirilmiştir. Cinsiyet tayini için karın bölgesinden yapılan diseksiyon sonrasında gonadlar makroskobik olarak incelenmiştir. Gonadların büyüklüğü, şekli ve rengi gibi morfolojik özellikler cinsiyetin

belirlenmesinde temel kriterler olarak kullanılmıştır (Geldiay & Balık, 2009; Freyhof & Brooks, 2011).

2.3. Veri Setinin Hazırlanması

Toplanan veriler, makine öğrenmesi algoritmalarının analizine uygun olacak şekilde dijital formata aktarılmış ve Weka 3.8.5 yazılımı kullanılarak işlenmiştir. Her birey için toplam boy, standart boy, çatal boy, ağırlık ve cinsiyet bilgilerini içeren bir veri seti oluşturulmuştur. Elde edilen veri seti rastgele olarak %80 eğitim ve %20 test alt kümesine ayrılmıştır. Bu ayrım, modellerin genellenebilirliğini ve doğruluğunu test etmek için kullanılan yaygın bir uygulamadır (Sokolova & Lapalme, 2009).

2.4. Uygulanan Makine Öğrenmesi Modelleri

Çalışmada, balıkların cinsiyet sınıflandırmasını gerçekleştirmek amacıyla dört farklı makine öğrenmesi algoritması tercih edilmiştir:

Lojistik Regresyon (Logistic Regression, LR), ikili ve çok sınıflı sınıflandırma problemlerinde yaygın olarak kullanılan istatistiksel bir modeldir. Doğrusal bir karar sınırı oluşturarak, özellikler ile hedef değişken arasındaki olasılıksal ilişkiyi modellemektedir (Hosmer & Lemeshow, 2013). Özellikle veri setlerinde değişkenler arasındaki ilişki doğrusal olduğunda etkili sonuçlar vermektedir.

Destek Vektör Makineleri (Support Vector Machines, SVM), sınıflar arasında maksimum marjini sağlayan optimal hiperdüzlemi bulmaya dayanan güçlü bir makine öğrenmesi algoritmasıdır. Cortes ve Vapnik (1995) tarafından geliştirilen bu yöntem, özellikle yüksek boyutlu veri kümelerinde ve doğrusal olmayan problemlerde (çekirdek hilesi kullanılarak) başarılı sonuçlar vermektedir.

Çok Katmanlı Algılayıcı Sinir Ağı (Multilayer Perceptron Neural Network, MLPNN), ileri beslemeli yapay sinir ağlarının temel bir uygulamasıdır. Girdi katmanı, bir veya daha fazla gizli katman ve çıktı katmanından oluşan bu model, doğrusal olmayan karmaşık ilişkileri öğrenme konusunda oldukça başarılıdır (Bishop, 1995). Özellikle büyük veri setlerinde derin öğrenme modellerinin temelini oluşturmaktadır.

Radyal Tabanlı Fonksiyon Sinir Ağı (Radial Basis Function Neural Network, RBFNN), aktivasyon fonksiyonu olarak radyal tabanlı fonksiyonlar (genellikle Gaussian fonksiyonu) kullanan özel bir sinir ağı mimarisidir. Lowe ve Broomhead (1988) tarafından geliştirilen bu yöntem, lokal örüntüleri yakalama ve enterpolasyon yeteneği ile özellikle kümeleme problemlerinde etkili sonuçlar vermektedir.

2.5. Performans Değerlendirme Ölçütleri

Sınıflandırma algoritmalarının başarısı, çok sınıflı karışıklık matrisi (confusion matrix) temel alınarak değerlendirilmiş ve performans ölçütleri olarak doğruluk (accuracy), kesinlik (precision) ve duyarlılık (recall) metrikleri kullanılmıştır. Doğruluk, modelin genel performansını yansıtan bir ölçüt olup, doğru tahmin edilen örneklerin toplam örnek sayısına oranını ifade etmektedir. Kesinlik ise belirli bir sınıf için yapılan pozitif tahminlerin doğruluk oranını gösterirken, duyarlılık gerçek pozitif örneklerin ne kadar başarılı şekilde tespit edildiğini ortaya koymaktadır. Bu üç metrik, sınıflandırma modellerinin performansını farklı boyutlarda değerlendirmekte ve birbirini tamamlayıcı nitelik taşımaktadır. Çalışmada, bu metrikler karşılaştırmalı olarak analiz edilmiş ve modellerin güçlü ve zayıf yönleri bu kapsamlı değerlendirme çerçevesinde ortaya konmuştur (Sokolova & Lapalme, 2009).

BULGULAR ve TARTIŞMA

Uygulanan makine öğrenmesi modellerinin sınıflandırma performansları Tablo 1 ve Tablo 2'de sunulmuştur.

Tablo 1. Çok Sınıflı Karışıklık Matrisi Sonuçları

Model	Doğru Pozitif	Yanlış Pozitif
Lojistik Regresyon	31	14
SVM	35	10
MLPNN	30	15
RBFNN	28	17

Tablo 2. Performans Ölçütleri (%)

Model	Doğruluk	Kesinlik	Duyarlılık
Lojistik Regresyon	68.90	72.50	70.20
SVM	70.00	75.30	73.80
MLPNN	63.50	68.20	65.40
RBFNN	60.70	65.10	62.30

Sonuçlara göre, Destek Vektör Makineleri (SVM), en yüksek doğruluk ve kesinlik değerlerini elde etmiştir. Bu durum, SVM'nin özellikle veri miktarının sınırlı olduğu çalışmalar için etkili bir yöntem olduğunu göstermektedir. Lojistik regresyon da benzer şekilde başarılı sonuçlar üretmiş, ancak karmaşık örüntüleri tanıma konusunda SVM kadar etkili olmamıştır.

Yapay sinir ağı tabanlı modeller olan MLPNN ve RBFNN, sınıflandırmada nispeten daha düşük performans göstermiştir. Bu durum, daha karmaşık yapılar olan bu modellerin yeterli eğitim verisi sağlanmadığında aşırı öğrenme (overfitting) eğilimine girmesiyle açıklanabilir. Bununla birlikte, veri setinin genişletilmesi ve parametre optimizasyonu ile bu modellerin performanslarının artırılması mümkündür.

SONUÇ

Bu çalışmada, *Atherina boyeri* türüne ait morfometrik ölçümler ve cinsiyet bilgileri kullanılarak farklı makine öğrenmesi algoritmaları ile cinsiyet sınıflandırması yapılmış ve model performansları karşılaştırılmıştır. Sonuçlar, makine öğrenmesi temelli yöntemlerin, balık biyolojisi ve popülasyon izleme çalışmalarında kullanılabilirliğini açıkça ortaya koymaktadır.

Özellikle Destek Vektör Makineleri (SVM), yüksek doğruluk ve güvenilirlik sağlayarak, gelecekte bu tür ekolojik ve biyolojik analizlerde tercih edilebilecek güçlü bir araç olduğunu göstermiştir. Sınırlı veri setlerinde dahi başarılı sonuçlar elde edilmesi, bu yöntemin esnekliğini ve genelleme kapasitesini ortaya koymaktadır.

Gelecekte yapılacak çalışmalarda, daha büyük örnekleme grupları ve derin öğrenme (deep learning) modelleri ile sınıflandırma doğruluğunun artırılması hedeflenebilir.

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DEVELOPMENT OF BRAIN COMPUTER INTERFACE SOFTWARE BASED ON DETECTION OF EEG SIGNALS WITH NEW GENERATION SENSORS

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ABSTRACT
Today, human-machine interaction is increasing day by day with the effect of artificial intelligence. This increase case our communication with machines and requires machines to work simultaneously with human characteristics. In order to facilitate this synchronization, this study examines the human brain and its electrical activities. Electroencephalogram (EEG) data, which is one of the bioelectrical states that occur in the brain while performing operations such as thought activities and discrimination, are analyzed. Due to the complexity and non-linearity of these electrical data in the brain, various electrode systems have been investigated and the new generation Neurosky Mindwave EEG sensor headset, which is useful in daily life, has been used. The TGAM module in the Neurosky Mindwave EEG sensor headset developed by Neurosky was investigated, which is used to detect EEG signals over the frontal lobe. In addition to the TGAM module, the sub-band states of the ThinkGear chip, which enables the detection of sub-bands in the oscillations of EEG signals, were examined. A uniquely developed Brain Computer Interface (BCI) was designed with C# programming language that enables the acquisition of these sub-bands and other hardware data used in the headphones. With this BCI and Neurosky Mindwave, EEG signals from the brain were statistically analyzed. As a result of the analysis, it was understood that these signals will be interpreted in human machine interaction and simultaneous interaction will be established.
Keywords: EEG, Brain Neural Activities, Neurosky Mindwave, BCI

1. INTRODUCTION

In recent years, the place and importance of machines and robots, with which we actively interact in our daily lives, have reached a significant level. Today, the rapid advancement of human-machine interaction has led to the development of technologies that communicate between humans and machines. In parallel with these developments, sensor structures have developed in brain-interactive technologies. These sensors are of great importance in measuring cognitive activity. In addition, the development of these sensors and their efficient application necessitated a detailed examination of the biological structure of the brain. It is one of the most important regions of the brain and is used to touch, hear, see, etc. brain structures in which many perceptual activities are carried out have been examined (Tülay E.,2009;Başar E.,2004;Başar E.,1980). It is understood that there is limb control in the brain's transformation of perceptual activities into functions. In addition, it is understood that bioelectric signals Electroencephalogram (EEG)occur in certain parts of the brain in the formation of perceptual activities. It has been proven that in the case of perceptual activities, these signals are detected by biosensors and converted into meaningful data with the brain computer interface (BCI).

EEG sensor structures have developed in brain-interactive technologies. Sałabun W's work has also succeeded in obtaining the theoretical values of the EEG value with the FFT analysis of the value taken from the new generation EEG sensor (Sałabun W.,2014). Ramesh et al. showed what they had done. They examined the EEG signals received from the brain with the mindwave EEG sensing headset belonging to the Neurosky company. They determined that the EEG effect is an interaction between thoughts and emotions. In order to be able to detect using EEG signals, Labwiev develops a Brain Computer Interface to kill the environment and develops a dynamic tool for users to consume their usage(Ramesh S., Krishna M.G 2014) In this study, the general structure of the brain was examined and the EEG signals formed in the brain in case of perceptual activities and the formation of their sub-bands were examined.The regions where the EEG signals occur were examined, and the data to be perceived from there were obtained using the new generation Neurosky Mindwave EEG sensor headset, which was developed differently from the standard EEG electrode system in clinics.

A BCI was designed to extract EEG signals and subbands from these data, and to analyze and analyze them meaningfully. This brain computer interface design was originally developed with a C# programming language. In the design, a visual design is created and the information received is interpreted and presented to the user.

2. MATERIAL AND METHODOLOGY

2.1. Material

In this study, the structure of the human brain was examined and EEG signals and subbands were obtained with the Neurosky Mindwave EEG sensor headset. By analyzing these data with a BCI software developed in C # environment, the cognitive activities of humans were understood.

2.2. Method

It has been obtained during the literature studies on the subject that there is a connection between the EEG signals formed in the human brain and human cognitive activities. The generalizability of the data in the projects was determined as a method as a result of the research

on the compatibility with the subject. The methods obtained during the literature study were made applicable for this study.

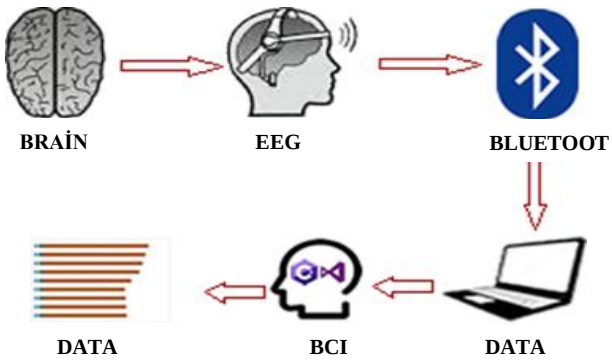


Figure 2.1: Flow Chart of The General System.

The brain consists of 2 parts. They consist of the cerebral cortex (cerebral cortex), which is called the hemisphere, which means hemisphere, and the cerebral cortex, which means the cerebral cortex. In the cerebral cortex, perceptions of the outside world are realized through the senses (hearing, sight, smell, etc.). The hemisphere consists of 4 separate lobes, each of which is separate from each other: parietal (P) lobe, temporal (T) lobe, frontal (F) lobe, and occipital (O) lobe.

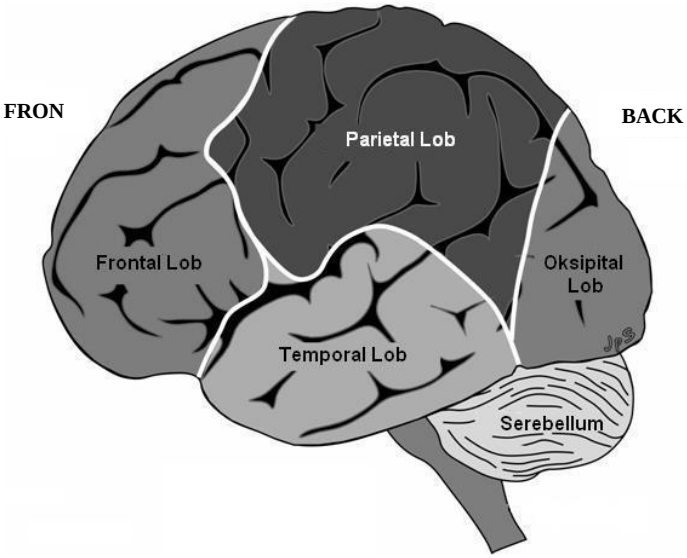


Figure 2.2: The main lobes of the brain (Tülay E., 2009)

Each lobe is specialized for separate tasks. Figure 2.2 shows the locations of the lobes in the brain. The tasks that these lobes perform in general are known. Frontal lobe: It is actively used in decision making, controlling feelings and finding solutions to problems. Parietal lobe: It is used in the case of making sense through sight and touch. Temporal lobe: used for hearing, speech and long-term use. Occipital lobe: It is used effectively in visual perception (Tülay,2009).EEG is the display state of the signals formed by taking the differences of electrical potentials formed by the interaction of billions of neurons in the brain with each other and converting them into digital data. It is a word of Greek origin, meaning "Brain Electrical Picture". The electrical change of the brain was investigated by Richard Caton for the first time in 1875. However, the observation made by Richard Cato is not important for humans, since it

takes place on animals. The first study on the human brain was carried out by Hans Berger in 1929. The EEG sample recorded during the analysis process carried out within the in this study is shown in Figure 2.3

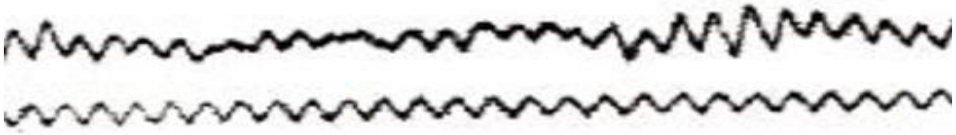


Figure 2.3: First EEG recording published by Hans Berger (Tülay E., 2009)

EEG Oscillations: In the formation of EEG waves, it is formed by the overlapping of more than one wave whose frequency ranges differ from each other. This is called the superposition method. Generally, the frequency of the waves goes down to at least 0.5 Hz and rarely exceeds 100 Hz. Measured amplitude measurements vary in the range of 2 μV -200 μV. Since these waves overlap in the EEG recording made as raw data, they cannot be detected directly. After filtering these waves, each wave (subband) can be observed on its own. These are also called EEG subbands. The general characteristics of these subwaves are shown in Table 1.

Table 1. Five Types of EEG Signals And Their Characteristics

EEG Signal	Amplitute (uV)	Frequency Hz	Occurrence State
Delta	20-200	0,6 -4	Sleep state, non-rapid eye movements
Theta	5-100	4-8	in nervous situations
Alpha	2-10	8-13	After closing the eyes at rest
Beta	1-6	13-30	in case of thinking
Gamma	<2	30-100	In the state of the brain working fast in a short time

3. HARDWARE ARCHITECTURE

The main materials and equipment generally used in this study consist of the equipment shown in the flow chart of the project in the method section. These; It is a Neurosky Mindwave EEG sensor headset used as a biosensor and a bluetooth computer used for wireless communication, which works integrated with the headset, and a laptop computer used for data processing.

3.1 Mindwave EEG Sensor

NeuroSky company is a Brain-Computer Interface technology manufacturer for consumer product applications founded in 2004 in Silicon valley, California. The company offers electroencephalography and electromyography technologies to users and developers by designing and adapting them to suit the consumer market in various fields such as entertainment, education, automotive and healthcare (EEG Headsets 2024). The headset is able to decompose EEG brain signals and EEG subbands such as Alpha, Beta, Gamma, Theta, Delta, Focusing and Thinking, which are among the intertwined EEG oscillations, through filters through the TGAM module. EEG sensing headphone consists of 6 parts mechanically. It is understood that it consists of headband (supporting), dry electrode (signal receiver), battery area, power switch section, earphone section and ear neutralization sections (EEG headsets 2024).

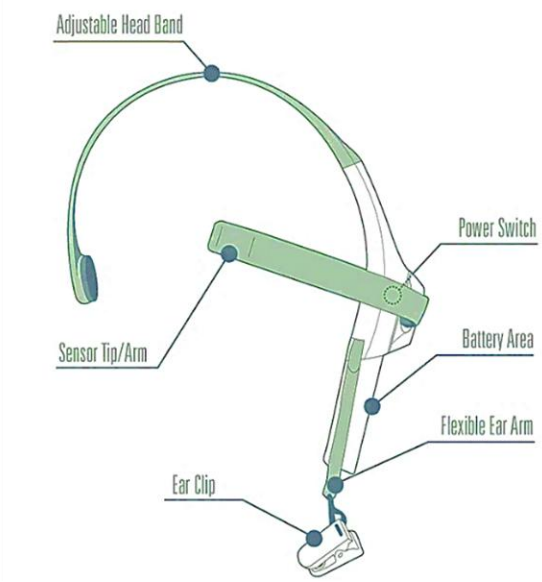


Figure 3.1: Neurosky mindwave EEG sensor headphone internal structure (EEG headsets 2024).

Neurosky EEG Sensor Headset Features:

1. Data Outputs: RAW EEG Signal, Meditation, Attention, Delta, Theta, high Alpha,low Alpha, high Beta, low Beta and Gamma waves are additional algorithms available in SDK.
2. Dimensions: TGAM1 Module: TGAT1 Chip: 9 x 9 x 1.6mm, Weight 130mg. 27.9 x 15.2 x 2.5mm,
3. Electronic equipment: 12-bit sampling rate of 512Hz, frequency range of 3-100Hz, Maximum Power Consumption: 15mA 3.3V, Operating voltage 2.97 ~ 3.63
4. UART (Serial):, 8-bit, No parity, 1 stop bit. 57600, 9600, 1200 baud.
5. TGAM1 uses Bluetooth v2.1 Class 2 module.

The ThinkGear chip is included in the Neurosky product and contains advanced technology that allows the device to interact with brain waves. The sensor, which touches the active reference points on the forehead and ears on the human head and detects the potentials there, processes all the data measured from here with filters, and these data (Alpha, Beta, Theta, Delta, Gamma, Metitation, Attitation) and hardware information are developed in digital form, software and applications. with users and developers (Reanaree, P., Tananchana, P., Narongwong wathana, N., Pintavirooj, C. 2016; Trivedi, K.R., Thakkar, R.A. 2016) The Bluetooth technology on the device is a module that can work with 2.4 GHz in at least 4.0 mode.The general features of the computer used for the realization of data processing and brain computer interface software is a laptop computer with an Intel core i5 processor 560M structure that can run at 2.5 Ghz, with 8 GB RAM memory, 500 Gb Hdd and -15.6" screen, working with W10 operating system.

4. SOFTWARE ARCHITECTURE

One of the most important parts developed In this study is software architecture. It is a standard structural notation that a software programmer uses to express an organized algorithm that enables him to use hardware effectively. In this study, the EEG data obtained from the EEG biosensor hardware were transferred to the computer environment with the help of the bluetoot on the TGAM module.A brain-computer interface based on visual design (robotiksistem 2024;

Kaya 2024) has been developed with the ThinkGear.dll library, which is the middle software in the technology it has developed to access the ThinkGear chip to process the raw data taken into the computer environment, and the C# language, which is an object programming language.

4.1. Developed Brain Computer Interface

In this study, brain computer interface software was developed using the C# programming language in the Visual Studio environment. Control objects used in the developed C# interface are Serial Port, Timer, ThinkGearWrapper and basic form control objects. (Luzheng Bi, Xin-An Fan, Yili Liu 2013).The visual design was planned and arranged accordingly, since it is aimed to give the data obtained based on the cognitive activities of the users in the interface in a meaningful way. (Ülker B., Tabakcioğlu M.B 2018)

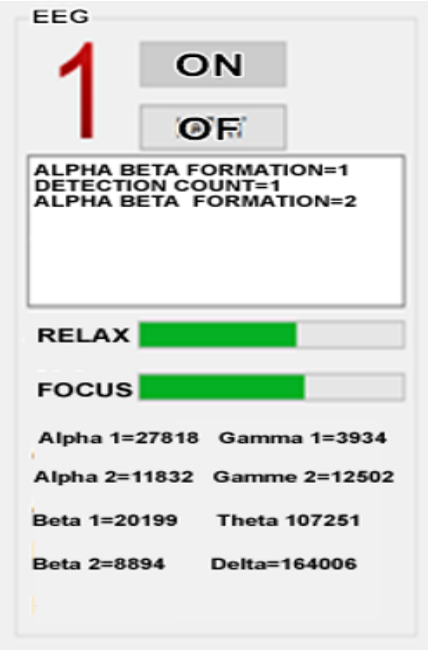


Figure 4.1: Brain computer Interface with C#

The algorithmic flowchart of the Brain Computer Interface, which was designed with the C# programming language in the Visual Studio environment, shown in Figure 4.1, is given in Figure 4.2. The software of the interface is written in C # programming language according to this algorithm.

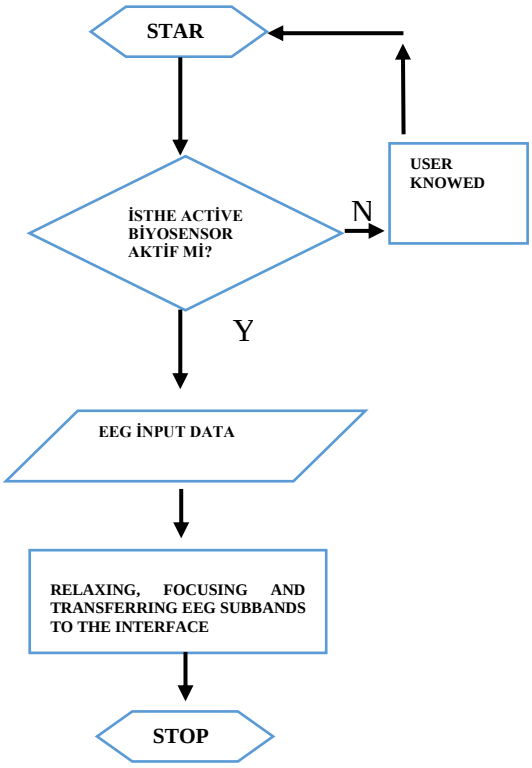
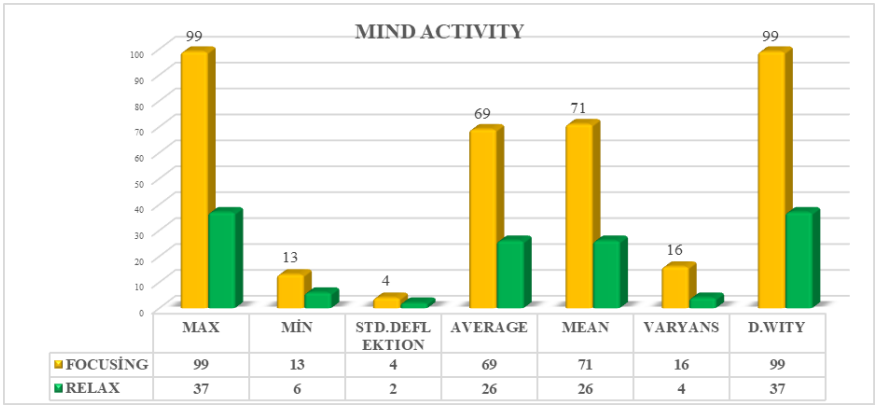


Figure 4.2: Brain Computer Interface Part 1 Flow Chart

ThinkGearNET object C# brain computer interface, which is provided by ThinkGear.dll from Neurosky mindwave EEG sensor headphone, was added to the form application software, allowing the electrical data from the electrode to be processed on the TGAM: ThinkGear ASIC Module. Received EEG subbands (alpha1, alpha2, Beta1, Beta2 Gamma1, Gamma2, Theta, Delta, Atitation and Meditation) ThinkGearWrapper thinkGearWrapper = new ThinkGearWrapper(); and transferred to the relevant areas in the first section of the brain-computer interface. With ThinkGearWrapper, not only EEG subbands but also Neurosky mindwave EEG sensor headphone hardware data, battery status, version, writing status, reading status and other errors are transferred to the first section of the interface, making it understandable for instantaneous information and correction in any negative situation. Attention (Attention) and relaxation (Meditation) data obtained with the brain-computer interface software developed In this the study were examined. They were acquired with multiline and analyzed according to basic statistical methods.



	MAX	MİN	STD.DEFLEKTION	AVERAGE	MEAN	VARYANS	D.WITY
FOCUSİNG	99	13	4	69	71	16	99
RELAX	37	6	2	26	26	4	37

Figure 4.3: Statistical Analysis of Focusing and Relaxation

Attention and relaxation rates, called mental (cognitive) activity, were analyzed graphically according to basic statistical methods. It is understood that they can be distinguished from each other.

5. CONCLUSION AND DISCUSSION

Using the information obtained in this study, it has been understood that the biosensor, which is used as a new generation, is quite efficient in the perception of human mind (cognitive) activity. The TGAM module, which was developed by Biosensor and Neurosky, is presented to users and developers as a new EEG sensor in the perception of mental activities. EEG data detected with a single electrode from the forehead by means of this sensor and the module inside, can be passed through necessary preprocessing and filters, and it can effectively give EEG subbands as well as determine attention and relaxation rates. It is not possible to receive EEG data directly from the headset, but can only be transferred to the computer environment by using wireless communication (bluetoot or Rf module). The data received to the computer environment via serial port wirelessly were analyzed with basic statistical methods by transferring the data to the brain computer environment through the ThinkGear.dll developed for the TGAM module and the ThinkGearNET object provided by the C# programming language. As a result of the analysis, it is understood from the ratios of the statistical analysis graphic data in Figure 4.3 whether the person is in a state of thinking.
It has been understood that these statistical data can be used for control in electronic environment. With the brain computer interface design, it is predicted that this information can facilitate the lives of those with limb loss by using their mental activities, or that people with paralysis can communicate more easily with the outside world with a brain-computer interface developed through mental activity and image processing methods (deep learning).

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STRAWBERRY FLOWER DETECTION USING THE HAAR CASCADE ALGORITHM

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ABSTRACT
Detecting strawberry flowers plays a crucial role in yield estimation and resource allocation in agriculture. Traditional manual methods are being replaced by computer vision and object detection techniques, which enhance accuracy and significantly reduce processing time. In this study, a Haar Cascade-based model was developed to automate strawberry flower detection. The model was trained using cropped positive and negative samples extracted from 600×600 pixels original images at various resolutions (24×24, 50×50, 100×100, 224×224, and 256×256 pixels). To optimize performance, several image processing techniques were applied using the OpenCV library, including resizing, grayscale conversion, dilation, Gaussian blurring, and histogram equalization. Experimental results demonstrated that the highest F1 score was achieved with 224×224 pixels input images, indicating the most balanced performance between Precision and Recall. While the 256×256 resolution resulted in the highest Precision (%97.68), it also led to a decrease in Recall (%84.77), suggesting a trade-off between false positives and false negatives. These findings highlight the significant impact of input image resolution on object detection accuracy. This study demonstrates the feasibility of computer vision-based object detection techniques in agricultural applications and underscores the importance of optimization strategies in enhancing model performance.
Keywords: Haar Cascade classifier, Object detection, Strawberry flower

1. INTRODUCTION

Strawberries are a widely grown and economically significant fruit worldwide, contributing substantially to the global agricultural economy (Hernández-Martínez et al., 2023). Recently, there has been increasing interest in developing automated systems for strawberry cultivation management, focusing on aspects such as fruit ripeness prediction and harvest optimization (Park & Kim, 2021; Hernández-Martínez et al., 2023). This growing trend aligns with broader advancements in smart agriculture, where artificial intelligence and machine learning play an essential role (Shaikh et al., 2022). However, detecting and monitoring strawberry flowers, which are essential for the next production period, remains a relatively underexplored yet crucial aspect of strawberry cultivation.

Advancements in computer vision and artificial intelligence have enabled object tracking algorithms to detect strawberry flowers accurately and reliably. These advancements enhance the ability to predict fruit yield in precision agriculture applications. Studies have shown highly effective results in fruit flower detection. For example, Chen et al. (2019), developed an automatic strawberry flower detection system using the Faster R-CNN network and transfer learning from ImageNet, ensuring accurate strawberry flower detection. Lin and Chen (2018), proposed a Faster R-CNN-based strawberry flower detection algorithm, considering shooting distance, flower overlap, and complex backgrounds. Additionally, Wang et al. (2022), developed a DSE-YOLO (Detail-Semantics Enhancement You Only Look Once) model to detect multi-stage strawberries, achieving an average mAP (mean Average Precision) and F1 score of 86.58% and 81.59%, respectively.

This study aimed to develop a model for real-time detection of strawberry flowers using the Haar Cascade Classifier, a machine learning algorithm chosen for its computational efficiency and suitability for real-time applications compared to more complex deep learning models.

2. MATERIALS and METHODS

2.1. Data Acquisition

The dataset was obtained from a strawberry cultivation area in Uludere village, Bilecik province. The images were captured using smartphones (Xiaomi Redmi Note 8 and Apple iPhone 8). The dataset consists of cropped images of strawberry flowers in positive images, positive images, negative images (strawberry plant images without flowers), and test images (Table 1).

Table 1. Data set

Cropped (Flower) Images	Positive Images	Negative Images	Test Images
843	504	600	366

2.2. Experimental Design

The dataset was used in the Cascade-Trainer-GUI program to train an object detection model with the Haar Cascade Classifier algorithm. Cropped strawberry flower images were trained at five different scales (24×24, 50×50, 100×100, 224×224 and 256×256 pixels). The trained models were exported to an XML file for real-time object detection and testing using OpenCV's "CascadeClassifier" algorithm.

2.3. Image Preprocessing

Using the OpenCV library, various image preprocessing techniques were applied to the dataset, which consisted of cropped, positive, and negative images. In the initial stage, positive and negative images were converted to grayscale and resized to 600×600 pixels. This process involved several techniques, including resizing, grayscale conversion, dilation, Gaussian blurring, and histogram equalization (Fig.1). Gaussian blurring was applied to reduce image

noise and smooth out variations that could lead to false detections, while histogram equalization was used to enhance contrast, making key features more distinguishable for the classifier.

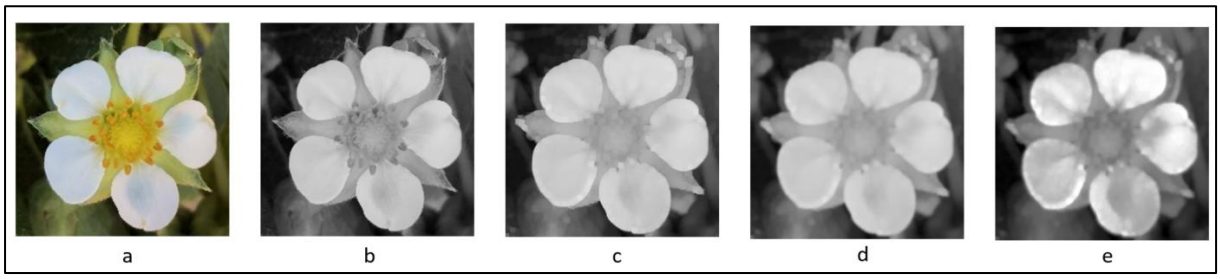

Fig. 1. A flower pre-processing. (a) Resize, (b) Gray scale, (c) Dilation, (d) Gaussian blurring, (e) Histogram equalize

2.4. Haar Cascade Classifier

The Haar Cascade Classifier is a machine learning algorithm developed by Paul Viola and Michael Jones in 2001 for face detection. This algorithm is also used in many other object detection applications besides face detection (Balabanov et al., 2020). The Haar Cascade Classifier is a machine learning-based object detection method that trains the classifier using Haar-like features and the AdaBoost algorithm to identify the target object in an image. Each stage of the classifier labels a specific region, defined by the current position of the window, as positive or negative. A positive label indicates that the specified object is present, while a negative label indicates that the object is not present in the image (Bai et al., 2024).

2.5. Evaluation Metrics

Evaluation metrics provide an objective way to assess machine learning models and help understand how effectively they solve the problem. Precision is defined as the ratio of the number of correctly detected objects to the total number of detected objects. Recall is defined as the ratio of the number of correctly detected objects to the actual number of objects in the image. The F_1 Score is calculated as the harmonic mean between Precision and Recall, and it is essential to determine these values.

$$Precision = \frac{TP}{TP + FP} \tag{1}$$

$$Recall = \frac{TP}{TP + FN} \tag{2}$$

$$F_1\,Score = 2 * \frac{(Precision * Recall)}{(Precision + Recall)} \tag{3}$$

Where;

True Positive (TP): Refers to correctly identifying an image that contains a real strawberry flower.

False Positive (FP): Refers to incorrectly identifying an image that does not contain a strawberry flower as one that contains it.

False Negative (FN): Refers to failing to identify an image that contains a strawberry flower.

3. RESULTS

This study trained and tested five different models built with the Haar Cascade Classifier algorithm using the strawberry flowers dataset. The test results of the five different models are shown in blue rectangular boxes in Fig. 2.

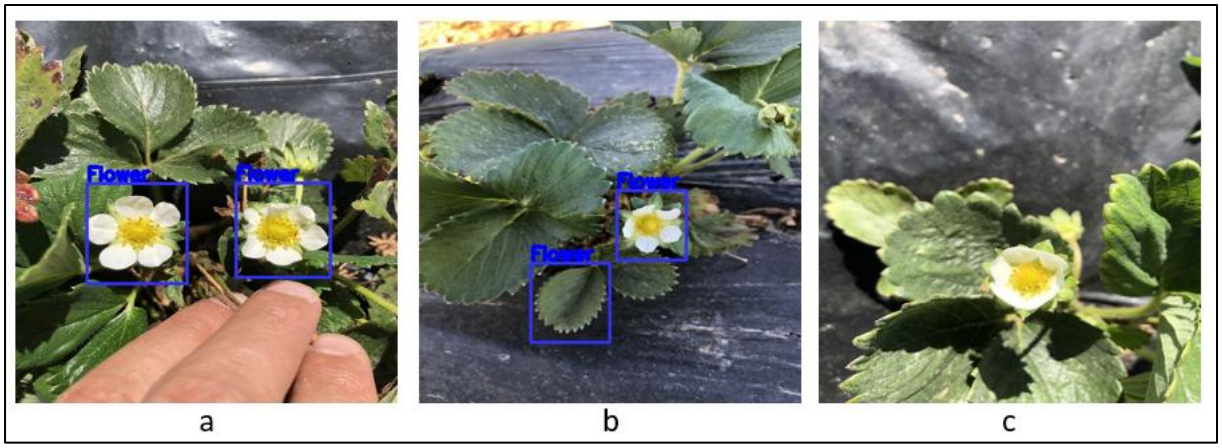

Fig. 2. Test results examples: (a) True positive, (b) False positive, (c) False negative

The study's findings reveal how the model's performance varies with different dimensions (Table 2.). The 24×24 size model achieved a high precision rate of %96.90 but had a relatively lower recall of %85.52, indicating that it missed some objects. The F_1 Score for this size was %90.86, reflecting a balanced performance. At the 50×50 size, precision was %94.85 while recall was %85.52, with an F_1 Score of %89.94, suggesting a similar performance to the previous size. For the 100×100 size, Precision slightly decreased to %93.97, while recall increased to %87.90, indicating improved detection of true positives. The F_1 Score for this size was %90.83. The 224×224 size showed a significant performance improvement, with precision rising to %95.13 and recall to %89.49, resulting in the highest F_1 Score of %92.22. However, at the 256×256 size, precision reached its peak at %97.68, but recall decreased to %84.77, with an F_1 Score of %90.77. This indicates that while the model worked with very high precision at this size, it missed some objects. Overall, larger sizes improved precision rates but led to a decrease in recall in some cases.

Table 2. Evaluation Metrics Results with Different Pixels Sizes

Pixel Size (px)	Precision (%)	Recall (%)	F_1 Score (%)
24×24	96.9	85.52	90.86
50×50	94.85	85.52	89.94
100×100	93.97	87.9	90.83
224×224	**95.13**	**89.49**	**92.22**
256×256	97.68	84.77	90.77

Overall, the impact of image size on model performance is clearly demonstrated. Larger sizes generally provide higher precision, while a decrease in recall is observed. F_1 Score has been used as an important metric to evaluate the overall performance of the models by reflecting the balance between these two metrics.

4. CONCLUSION

In this study, where the Haar Cascade Classifier algorithm was used for real-time detection of strawberry flowers, the recall and F_1 Score values demonstrated promising results for real-time flower detection. Overall, larger image sizes achieved a balance between precision and recall, with the highest dimension of 256×256 showing a decrease in recall. These results indicate that the model's performance metrics changed with increasing image size.

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DOMATES BİTKİSİNDE FARKLI SULAMA DÜZEYLERİ VE FERTİGASYON UYGULAMALARININ STOMA DİRENCİ İLE VERİME ETKİLERİNİN BELİRLENMESİ

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Özet
Çalışma 2015 yılında domates bitkisinde, su kısıntısı ve fertigasyon tekniklerinin stoma direncine olan etkilerinin tespit edilebilmesi amacıyla yürütülmüştür. Tam sulama ve kısıntılı sulama konuları ile (I_{100}: tam sulama, I_{70} ve I_{50}: kısıntılı sulama) fertigasyon uygulama yöntemlerinin (F_1: enjeksiyon pompası, F_2: ventüri, F_3: basınç farkı) etkileri test edilmiştir. Araştırma sonuçlarına göre farklı fertigasyon teknikleri ile sulama konularının verim üzerine etkisi istatistiksel olarak önemli bulunmuştur ($P < 0.01$). En düşük stoma direnci içeriği enjeksiyon pompası yöntemi ile gübrenin verildiği (F_1) ile I_{100} tam sulama konusundan elde edilmiş ayrıca verilen sulama suyu miktarlarında azalma sonucu stoma direnci değerlerinin arttığı belirlenmiştir. Elde edilen domates verimi değerleri ile stoma direnci değerleri arasında önemli ilişkiler ($P < 0.01$) belirlenmiştir. En düşük stoma direnci içeriğinin F_1I_{100} konusunda 26.07 s m^{-1} ve en yüksek ise F_2I_{50} konusunda 104.58 s m^{-1} olarak tespit edilmiştir. Çalışma sonuçlarına göre stoma direnci değerlerinin sulamaların planlanmasında kullanılabileceği, kanıtlanmıştır. Stoma direncinin su stresine tepkisi, suyun kıt olduğu durumlarda kullanılabilir bir parametre olduğu belirlenmiştir.
Anahtar Kelimeler: Domates, gübreleme tekniği, stoma direnci, kısıntılı sulama

DETERMINATION OF THE EFFECTS OF DIFFERENT IRRIGATION LEVELS AND FERTIGATION APPLICATIONS ON STOMA RESISTANCE AND YIELD IN TOMATO PLANT

Abstract

This study was conducted in 2015 to determine the effects of deficit irrigation and fertigation techniques on stomatal resistance in tomato crop. The effects of fertigation application methods (F_1: injection pump, F_2: venturi, F_3: pressure difference) with full irrigation and deficit irrigation treatments (I_{100}: full irrigation, I_{70} and I_{50}: curtailed irrigation) were tested. According to the results, the effects of different fertigation techniques and irrigation treatments on yield were found statistically significant ($P < 0.01$). The lowest stomatal resistance content was obtained from I_{100} full irrigation treatment where fertilizer was applied by injection pump method (F_1) and it was also determined that stoma resistance values increased as a result of the decrease in the amount of irrigation water applied. Significant relationships ($P < 0.01$) were determined between tomato yield and stomatal resistance values. The lowest stomatal resistance content was 26.07 s m^{-1} in F_1I_{100} and the highest was 104.58 s m^{-1} in F_2I_{50}. According to the results, it was proved that stoma resistance values can be used in irrigation scheduling. The response of stomatal resistance to water stress was determined to be a useful parameter when water is scarce.

Key words: Tomato, fertigation techniques, stoma resistance, deficit irrigation

Giriş

Domates Önemi ve Türkiye ile Dünya'da Üretimi

Amerika'nın keşfinden (15. yüzyıl) sonra Avrupa'ya getirilen ve Osmanlı'nın 19. yüzyılın sonlarına doğru tanıştığı domates bitkisi, günümüzde dünyada en çok tüketilen sebzelerin başında gelmektedir. Ticari anlamda çok büyük bir pazara sahip olan domatesin günümüzde 9.000'den fazla çeşidi olduğu tahmin edilmektedir (HortiTürkiye, 2018).

Araştırmalar, teknik olarak meyve kategorisinde bulunan domatesin sağlık açısından çok sayıda faydası olduğunu göstermektedir. ABD Tarım Bakanlığı (USDA) tarafından yayınlanan verilere göre, 22 kalorilik orta boy taze bir domates, potasyum, A vitamini ve antioksidan likopenin yanı sıra, bir gramdan fazla life sahiptir (Durmuş, 2018).

Domates önemli bir vitamin kaynağıdır. Bu vitaminler arasında ilk sırada C vitamini bulunmaktadır. Ayrıca domatesin yapısında potasyum, folat ve K vitamini de bulunmaktadır. Domatesler D3 vitamininin yapıtaşı olarak bilinen provitamin D3 ya da 7-dehidrokolesterol olarak tanımlanan maddeyi yapraklarında bulundururlar. Doğal koşullarda olgun domateslerde provitamin D3 birikmez. Domatesin en çok yetiştirilen sebze olmasının sebepleri, hem insanların beslenme alışkanlıklarının çok önemli bir parçası olması hem de sanayide üretilen salça ya da ketçap gibi birçok ürünün hammaddesi olarak kullanılması gösterilmektedir. Domates kolaylıkla taze, konserve, salça ve soslar içerisinde yer almakta olup, farklı formlarda elde edilebilir ve aynı zamanda düşük bütçelere de uygundur (Demircan, 2023).

Dünya domates ekim alanı 2021 yılında bir önceki yıla göre %3.3 artarak yaklaşık 51.7 milyon dekara ulaşmıştır. Dünya domates üretimi ise bir önceki yıla göre %2,4 artarak yaklaşık 189.1 milyon ton olarak gerçekleşmiştir (FAO, 2023).

Çin %22'lik ekim alanı ile 2021 yılında Dünya domates üretiminde en yüksek paya sahiptir. Sonrasında sırası ile Hindistan ve Nijerya (%16.4), Pakistan (%3.2) ve Türkiye (%3.1) yer almaktadır. Dünya domates verimi 2021 yılı itibarıyla hektar başına yaklaşık 36.6 ton olup, AB ülkelerinin verimde ön sıralarda olduğu görülmektedir. Dünya domates verimi 2021 yılı sıralamasında Hollanda 475.7 ton ha^{-1} ile ilk sıradadır. Hollanda'yı 448.7 ton ha^{-1} ile Belçika ve 436.5 ton ha^{-1} ile İsveç takip etmektedir (Demircan, 2023).

Domates Türkiye'de üretimi en fazla yapılan sebze olup toplam sebze üretiminin 2022 yılında %41.2'sini oluşturmaktadır. Türkiye domates ekim alanlarına bakıldığında 2022 yılında bir önceki yıla göre ekim alanlarının yaklaşık %3,6 daraldığı görülmektedir. Türkiye'nin 2022 yılı toplam domates üretimi ise bir önceki yıla göre yaklaşık %0,7 azalarak 13 milyon ton olmuştur. Verim 2022'de bir önceki yıla göre %3 artarak 81.8 ton ha^{-1} olarak gerçekleşmiştir. Türkiye 2022 yılı domates üretiminin %61,2'si sofralık, %38.8'i ise salçalık olarak gerçekleşmiştir. Domates üretimi 2022 yılında en çok %30.7 ile Akdeniz, %22 ile Ege, %13.2 ile Doğu Marmara, %9 ile Batı Marmara Bölgeleri'nde gerçekleşmektedir (Demircan, 2023).

Su kaynağının kıt olduğu kurak ve yarı kurak bölgelerde suyun etkin kullanımı açısından sulamanın doğru bir şekilde yapılmasına olan ihtiyaç, araştırmacıları sulama programlamasında yeni teknolojilerin geliştirilmesi yönünde teşvik etmiştir. Bu amaçla, bitkideki su stresini de ortaya koyan bitkiye dayalı ölçümlerin kullanıldığı birçok yöntem geliştirilmiştir. En yaygın olarak kullanılan yöntemlerden; geleneksel ve otomasyona uygun olmayan yöntemler, yaprak veya ksilem su potansiyeli, stoma iletkenliği ve fotosentez ölçümü iken, sürekli ve otomatik ölçümü mümkün kılan yöntemler ise özsu akışı, gövde çapı ve yaprak turgoru gibi ölçümlerdir (Fernández ve Cuevas, 2010; Fernández, 2017).

Bitkilerin su stresi koşullarında verdikleri en önemli tepkilerden biri bitki yapraklarında yer alan stomalarını kapatarak transpirasyonla meydana gelen su kaybını azaltmalarıdır. Stoma direncini ya da tersi olan stoma iletkenliğini yaprak su içeriğinden daha çok toprağın su içeriği belirler (Taiz ve Zeiger, 2008). Toprak-bitki-atmosfer uzantısı boyunca suyun hareketi

tamamıyla evapotranspirasyon (ET)'un kontrolü altında olup bitkideki su hareketinde tahrik eden güç transpirasyondur. Suyun topraktan bitkiye, bitkiden atmosfere taşınması basınç gradyeni sonucunda meydana gelmekte, su azalan su potansiyeli doğrultusunda hareket etmektedir (Blum, 2011).

Stoma, bitki ve dış ortam arasındaki hayati bir geçiş noktasıdır ve bitkinin çevresel etmenlere verdiği tepkilerde merkezi bir rol oynar (Montoro ve ark., 2016). Yaprak, yüzeydeki stomatal gözenekler vasıtasıyla fotosentez için CO_2'yi yakalarken, kaçınılmaz olarak su kaybedilir. Genotiplere ve çevre koşullarına bağlı olarak stoma gözeneklerinin yoğunluğu, gözenek açıklığı ve bunların düzenlediği fotosentez ve transpirasyon oranları çeşitlilik gösterir (Lawson ve Blatt, 2014).

Stomaların, fotosentez ve bitki büyümesi için terleme ve CO_2 alımı yoluyla su kayıplarını düzenlemede önemli bir görevi vardır (Gerosa ve ark., 2012). Ayrıca stoma kontrolü kuraklık koşullarında su kullanımını optimize etmenin önemli bir fizyolojik yoludur (Makbul ve ark., 2011). Tarımda sınırlı su kaynaklarının verimli kullanımını geliştirmek için yaprak stoma iletkenliğinden taç iletkenliğine bitki su tüketiminin tahmini büyük önem taşımaktadır (Zhang ve ark., 2011).

Yapılan bu çalışmayla ülkemiz domates yetiştiriciliğinde fazla sulama suyu kullanımının önüne geçerek su tasarrufu sağlayabilmek ve su kısıntısı uygulamaları ile farklı fertigasyon uygulamalarının domates bitkisinde stoma direnci ile verime olası etkileri belirlenmiştir.

Materyal ve Metod

Çalışma Alanı İklim ve Toprak Özellikleri

Araştırma Alata Bahçe Kültürleri Araştırma Enstitüsü Müdürlüğü Tarsus Lokasyonu'nda 2014 yılında yapılmıştır. Araştırma yeri, deniz seviyesinden 60 m yükseklikte olup, 36°53′ enlem ve 34°57′ boylam arasında yer almaktadır. Deneme alanı Akdeniz iklim kuşağında kışlar ılık ve yağışlı, yazlar sıcak ve kurak geçmektedir. Deneme alanı iklim istasyonu verilerine göre, yörenin uzun yıllık yağış ortalaması 616 mm'dir. Bölgede uzun yıllık sıcaklık ortalaması 18.2°C'dir. En sıcak ay ortalaması Ağustos ayında 27.2°C, en soğuk ay ortalaması Ocak ayında 3.9°C'dir. Uzun yıllar ölçümlerine göre oransal nem ortalaması %70.2'dır. Uzun yıllar ortalamalarına göre yıllık buharlaşma ise 1478 mm'dir. En fazla buharlaşma 212.1 mm ile Temmuz ayında olmaktadır.

Deneme alanının fiziksel özellikleri, toprağın pH'sı 7.91 - 8.11; EC içeriği 0.914 - 1.028 dS m^{-1}; hacim ağırlığı 1.30 - 1.42 g cm^{-3}; tarla kapasitesi 29.64 - 30.70 g g^{-1}. solma noktası ise 12.71 - 19.75 g g^{-1} arasında belirlenmiştir. Deneme alanı topraklarının profil boyunca 0 - 30 cm kil, diğer katmanların siltli kil olduğu ve 60 cm profil derinliğindeki kullanılabilir su miktarı 201 mm olarak hesaplanmıştır. Tarla kapasitesi ve solma noktası su içerikleri ise derinlik olarak 245 mm ve 157 mm olarak belirlenmiştir. Ayrıca 3 farklı derinlikten (0 - 30, 30 - 60, ve 60 - 90 cm) bozulmamış toprak örnekleri alınarak yapılan hacim ağırlığı değerleri de her bir derinlik için ortalama 1.37 g cm^{-3} olarak elde edilmiştir.

Domates yapraklarında stoma direncini belirlemek için porometre (AP4 Delta-T) aygıtı kullanılmıştır. Ölçümler her bir parselin ortasında seçilen iki bitki üzerinde güneşi gören tam gelişmiş üst iki yaprağın altından ve üstünden açık hava koşullarında saat 12:00-14:00 arasında haftada bir sulamalardan önce yapılmıştır. Her bir porometre okumalarından önce aygıtın kalibrasyonu yapılmıştır. Kalibrasyon değerlerinden yararlanarak yaprağın alt ve üst yüzey dirençleri Clawson ve Blad, (1982) tarafından verilen aşağıdaki eşitlikle yaprağın ortalama stoma direnci hesaplanmıştır.

$$rs = \frac{r_{ü} + r_a}{r_{ü}\, x\, r_a}$$

Eşitlikte, rs: ortalama stoma direnci s cm^{-1}; rü: yaprağın üst yüzeyinin stoma direnci, s cm^{-1}; ra: yaprağın alt yüzeyinin stoma direnci, s cm^{-1}.

Araştırma Konuları ve Sulama Sistemi

Araştırmada son yıllarda yaygın olarak görülen domates sarı yaprak kıvırcıklığı virüsü (TYLCV) ve fusarium hastalığına dayanıklı Marmara F1 salçalık domates (*Solanum lycopersicum*) fidesi kullanılmıştır. Yaprakları meyveyi çok iyi örten bir çeşit olup meyve ağırlığı genel olarak 250-280 g arasında değişen ve görünüm olarak hafif basık olan bir çeşittir.

Çalışma tesadüf blokları bölünmüş parseller deneme desenine göre 3 tekerrürlü yürütülmüştür. Araştırmada üç farklı fertigasyon ekipmanları ana konuları (F_1: Enjeksiyon pompası, F_2: Ventüri, F_3: Basınç farkı) ve üç farklı sulama düzeyi ise alt konuları (I_{100}: Tam sulama, I_{70} ve I_{50}: Kısıntılı sulama) oluşturacak şekilde düzenlenmiştir. (I_{100}: Tam sulama konusu olup bir haftalık sulama aralığında 60 cm'lik toprak profilindeki eksik nemin tarla kapasitesine getirildiği konudur; I_{70} ve I_{50}: Kısıntılı sulama konuları ise I_{100} konusuna uygulanan suyun %70 ve %50'sinin uygulandığı konulardır.)

Domates bitkisinin sulanmasında damla sulama sistemi kullanılmıştır. Toprağın infiltrasyon özellikleri dikkate alınarak damlatıcı arası mesafe 40 cm ve damlatıcı debisi ise 4 L h^{-1} olan damlatıcılar, içten geçik ve basınç kontrollü olup her sıraya bir lateral gelecek şekilde düzenlenmiştir. Lateraller Ø16 mm dış çapında olup 1.0 mm et kalınlığında PE malzemeden üretilmiştir.

Uygulanan sulama suyu miktarı eşitliğe göre belirlenmiştir:

$$R = AxPx\Delta s$$

Burada;

R : Sulama suyu miktarı, lt

A : Parsel alanı, m^2

P : Islatılan alan yüzdesi, %

Δs: 60 cm derinlikteki eksik toprak su içeriği, mm

Islatılan alan yüzdesi sulama aralıklarında örtü yüzdesi olarak izlenmiş ve örtü genişliğinin sıra arası uzaklığa oranlanmasıyla ıslatma yüzdesi hesaplanmıştır. Örtü genişliği değeri 0.70 m değerine ulaştığında sabit olarak kabul edilmiştir.

Bulgular

Sulama Suyu Miktarı ve Verim

Domates bitkisinin araziye dikimden sonra tüm parsellere eşit miktarda 15.0 mm can suyu verilmiştir. Ayrıca belirli tarihlerde can suyu uygulamaları yapılmıştır. Konulu sulamalara domates bitkisinde parsellerde yaklaşık %70 çiçeklenme oluşumunun belirlendiği tarihte, 60 cm toprak profilindeki eksik nem tarla kapasitesine getirilerek başlanmış ve hasattan 10 gün önce son sulama yapılmıştır. Her üç fertigasyon konularında (F_1, F_2 ve F_3) üç farklı sulama düzeyinde (I_{100}, I_{70} ve I_{50}) 2015 deneme yılında 5 eşit sulama ve toplamda 12 konulu sulama uygulamaları yapılmıştır. Deneme süresince F_1, F_2 ve F_3 fertigasyon konularına I_{100} tam sulama düzeyinde toplam 397.9 mm sulama suyu uygulanmıştır. Aynı fertigasyon konularında I_{70} kısıntılı sulama uygulamasında toplam 303.4 mm ve I_{50} konusunda ise toplamda 240.4 mm sulama suyu verilmiştir.

Fertigasyon konuları ve sulama düzeylerine ait ortalama verim değerleri LSD gruplandırması Çizelge 1'de verilmiştir. Domates ortalama toplam verim değerleri 2803 - 4875 kg da^{-1} arasında değişmiştir. Enjeksiyon pompası olan fertigasyon yönteminde (F_1), ortalama toplam verim değerleri 3660 - 4875 kg da^{-1} arasında, venturi olan fertigasyon yönteminde (F_2), 2803 - 3721 kg da^{-1} ve basınç farkı olan fertigasyon yönteminde (F_3), 3760 - 4514 kg da^{-1} olarak belirlenmiştir. LSD gruplandırması sonucuna göre en yüksek verim enjeksiyon pompası ile fertigasyon yönteminin uygulandığı (F_1) I_{100} konusunda 4875 kg da^{-1} olarak belirlenmiştir. En düşük verim değerleri ise venturi fertigasyon yönteminin uygulandığı (F_2) I_{50} konusundan 2803 kg da^{-1} ve (F_2) I_{70} konusundan 2840 kg da^{-1} olarak elde edilmiştir. Basınç farkı yönteminin

uygulandığı fertigasyon yönteminde (F_3) en yüksek verim I_{100} konusunda 4514 kg da^{-1} olduğu sonucuna varılmıştır.

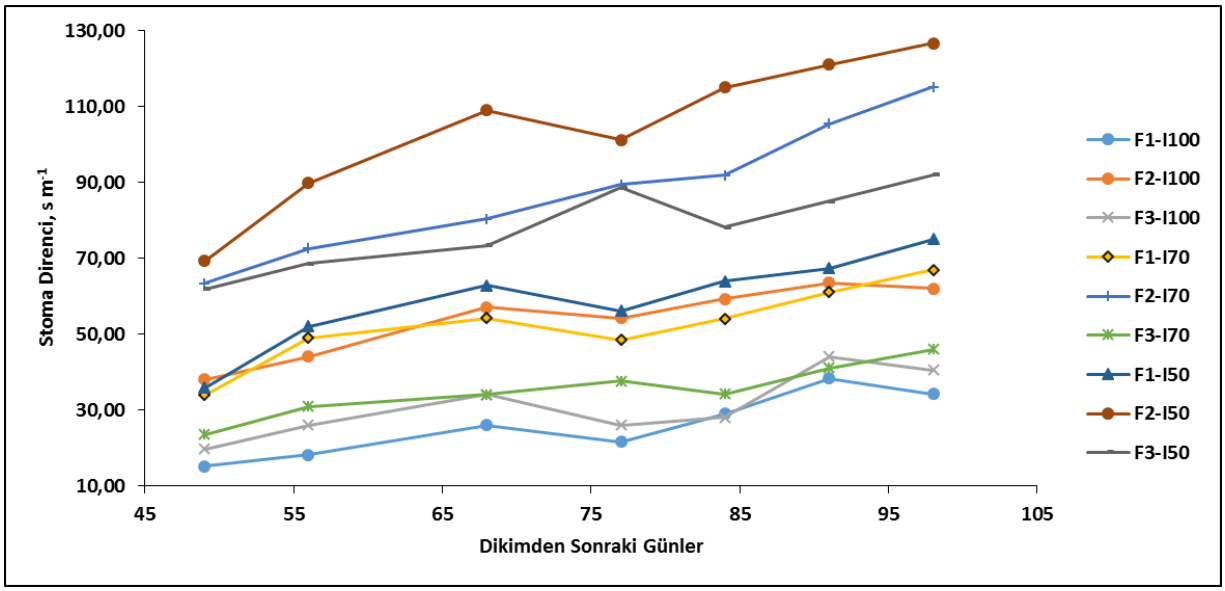
Çizelge 1. Fertigasyon ve sulama konularının verime ilişkin LSD gruplandırması

Fertigasyon Yöntemi	Sulama Konuları		
	I_{100}	I_{70}	I_{50}
F_1	4875 a	4049 d	3660 e
F_2	3721 e	2840 f	2803 f
F_3	4514 b	4263 c	3760 e
İstatistiksel Analiz	F*SK: LSD (0.05)=203.3; P=0.01**		

Gürbüz (2001), farklı sulama yöntemleri ile sulama suyu düzeylerinin domates bitkisi üzerinde ki etkilerini incelediği araştırmada, açık su yüzeyinde meydana gelen yığışımlı buharlaşma miktarlarını (k_1:0.35 – k_2:0.70 – k_3:1.05 ve k_4:1.40) kp esas almışlardır. Çalışma sonucuna göre en yüksek domates verimini damla sulamada kp:1.40 konusunda 3.538 kg da^{-1} olarak elde etmişlerdir. Papadopoulos (2000), azot gübresini geleneksel olarak toprağa ve fertigasyon uygulaması ile vererek farklarını inceledikleri araştırmada fertigasyon ile azot gübrelemesinde, geleneksel toprağa verilen gübreleme yöntemine göre %50 daha yüksek verim elde ettiklerini bildirmişlerdir.

Bitki Stoma Direnci

Bitki stoma direnci değerlerine ilişkin ölçümler, sulama uygulamalarıyla başlayıp hasata kadar sürdürülmüştür. Farklı fertigasyon ve sulama konularında stoma direnci (r_s) değerlerinin mevsim boyunca değişimi Şekil 1'de verilmiştir. Araştırma sonuçlarına göre domates bitkisinde en yüksek stoma direnci değeri, ventüri yöntemi ile gübrelemenin yapıldığı (F_2) kısıntılı sulama (I_{50}) konusundan ortalama olarak 104.58 s m^{-1} olarak elde edilmiştir. En düşük ortalama stoma direnci değeri ise enjeksiyon pompası fertigasyon yöntemi (F_1) ve tam sulama (I_{100}) konusundan 26.07 s m^{-1} olarak elde edilmiştir. Mevsim içerisinde sulama öncesi ortalama stoma direnci değerleri F_1 fertigasyon uygulamasında 26.07-59.00 s m^{-1} arasında, F_2 fertigasyon uygulamasında 54.00-104.58 s m^{-1} ve F_3 fertigasyon uygulamasında 31.14-78.28 s m^{-1} arasında değişmiştir.

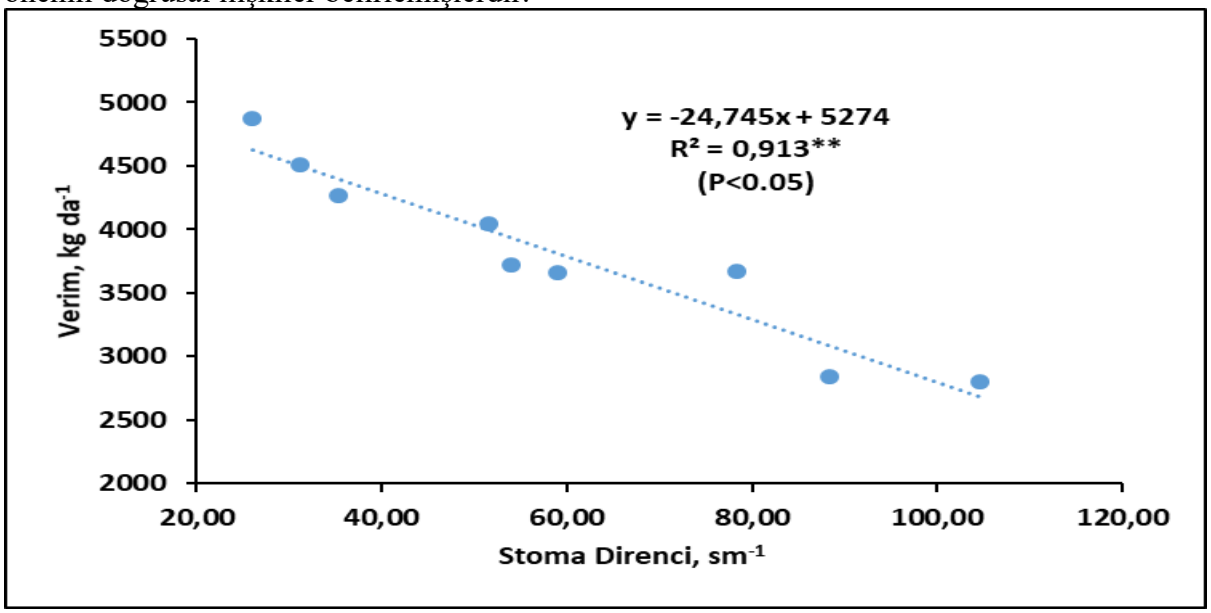


Şekil 1. Farklı fertigasyon ve sulama konularında stoma direnci değerlerinin mevsim boyunca değişimi

Domates bitkisinde sulama suyu miktarları arttıkça stoma direnci değerlerinde azalmalar elde edilirken daha az suyun uygulandığı su kısıntısı koşullarında ise daha yüksek değerler elde edilmiştir. Çamoğlu ve ark. (2019), su stresinin artmasıyla birlikte domates bitkisinde stoma iletkenliğinin belirgin bir şekilde azaldığını ifade etmişlerdir. Bu durum, bitkinin mevcut su içeriğini korumak için stomalarını kapatmasıyla ve suyun bitkinin dokularında tutulmasını sağlamasıyla ilişkilendirilmiştir. Bu bulgu, bitkilerin su stresine nasıl tepki verdiği ve bu stres durumunda stomaların rolünün ne kadar önemli olduğunu göstermiştir. Çamoğlu ve ark. (2024) Çanakkale ilinde biber bitkisinde su stresi ve sulama zamanının belirlenmesine yönelik çalışmalarında en yüksek stoma iletkenliği değerleri tam sulama konusundan elde etmişlerdir. (2017 yılında 609 mmol m^{-2} s^{-1}, 2018 yılında 582 mmol m^{-2} s^{-1}).

Verim ile Stoma Direnci İlişkisi

Çalışmada deneme konularından ele edilen stoma direnci değerleri ile verim değerleri arasındaki ilişkiler Şekil 2.'de verilmiştir. Stoma direnci değerleri ile verim arasında istatistiksel olarak doğrusal önemli ilişkiler bulunmuştur ($P < 0.01$). Bozkurt Çolak ve Yazar (2024) dolmalık biber bitkisinde yaptıkları çalışmada stoma direnci ile verim arasında $P<0.01$ önemli doğrusal ilişkiler belirlemişlerdir.



Şekil 2. Verim ile stoma direci (rs) arasındaki ilişki
(P<0.01 **) %1 önemli (P<0.05 *) % 5 önemli (P>0.05 ö.d.) önemli değil

Sonuç

Yapılan çalışma ile insan beslenmesinde en büyük paya sahip olan domates bitkisinde, damla sulama sistemlerinde kullanımı gün geçtikçe daha da yaygınlaşan farklı fertigasyon ekipmanları ile sulama düzeylerinin bitki stoma direnci üzerine olası etkileri belirlenmeye çalışılmıştır.

Sonuçlara göre domates bitkisinde sulama suyu miktarı arttıkça verim değerlerinde artışlar meydana gelmiştir. Stoma direnci değerleri sulama suyu miktarı ve fertigasyon ekipmanlarına göre farklılıklar göstermiştir. Bitki su stresi koşullarında daha yüksek stoma direnci değerleri göstermektedir. Ayrıca su stresinin olmadığı ve bitkinin sulama suyu miktarını tam aldığı konuda ise daha düşük stoma direnci değerleri elde edilmiştir. Enjeksiyon pompası fertigasyon yönteminde, diğer yöntemlere göre daha yüksek verim değerleri tespit edilmiştir. Domates verimi ile stoma direnci arasında önemli doğrusal ilişkiler bulunmuştur. En yüksek stoma direnci değeri F_2 venturi fertigasyon yönteminde %50 su kısıntısının yapıldığı konudan 104.58 s m^{-1} olarak elde edilmiştir. Sonuç olarak yüksek verim için domatesin rs'nin

26.07 s m^{-1} değeri arasında sulanması gerektiği belirlenmiştir. Araştırma sonunda elde edilen veriler ile domates bitkisi için en uygun fertigasyon yöntemi ve sulama düzeyi belirlenerek stoma direnci değerinin su stresini belirlemede sulama programlanmasında kullanılabileceği söylenebilir. Özellikle gelecek yıllarda olası su kaynaklarının azalmasında daha da önem kazanacak olan sulama programlaması ile su stres koşullarının belirlenmesinde stoma direnci değerleri kullanılabilir durumdadır.

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REÇİNE BAZLI KOMPOZİT MALZEMELERİN EKLEMELİ ÜRETİMİNDE SÜRDÜRÜLEBİLİRLİK PERSPEKTİFLERİ

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ÖZET
Eklemeli imalat (Eİ), özellikle stereolitografi (SLA) ve dijital ışık işleme (DLP) gibi tekne fotopolimerizasyon teknikleri, karmaşık ve yüksek çözünürlüklü reçine bazlı kompozit malzemelerin üretilmesi için güçlü bir araç olarak ortaya çıkmıştır. Küresel endüstriler daha sürdürülebilir üretim paradigmalarına doğru kaydıkça, bu gelişmiş üretim yöntemlerinin çevresel, malzeme ve enerji ile ilgili etkilerini değerlendirmek giderek daha önemli hale gelmektedir. Bu derleme makalesi, Eİ yoluyla reçine bazlı kompozit üretiminin sürdürülebilirlik yönlerinin kapsamlı bir incelemesini sunmaktadır. Hammadde seçimi, baskı işlemi sırasında enerji tüketimi, kürlenmemiş reçinelerin atık yönetimi ve termoset bazlı sistemlerin geri dönüştürülebilirliği ile ilgili zorluklar gibi temel faktörlere odaklanmaktadır. İşlevsel performansı korurken veya geliştirirken çevresel ayak izlerini en aza indirmeyi amaçlayan biyo-bazlı reçinelerin, doğal nano dolguların ve hibrit takviyelerin artan kullanımına vurgu yapılmaktadır. Buna ek olarak, makalede yaşam döngüsü değerlendirme (LCA) yaklaşımları ve yeniden kullanılabilirlik, demontaj için tasarım ve kapalı döngü malzeme akışları gibi döngüsel ekonomi stratejilerindeki son gelişmeler değerlendirilmektedir. Mevcut araştırma ve teknolojik eğilimleri sentezleyerek, fotopolimer bazlı Eİ'ı daha sürdürülebilir hale getirmenin hem zorluklarını hem de fırsatlarını tanımlamaktadır. Yeni nesil kompozit malzemelerin geliştirilmesinde çevreye duyarlı uygulamaların benimsenmesi için araştırmacılara, tasarımcılara ve üreticilere yol göstermeyi amaçlamaktadır.
Anahtar Kelimeler: Eklemeli imalat, Sürdürülebilirlik, Biyo-Bazlı reçineler, Yaşam Döngüsü Değerlendirmesi (LCA), Döngüsel tasarım

SUSTAINABILITY PERSPECTIVES IN ADDITIVE MANUFACTURING OF RESIN-BASED COMPOSITE MATERIALS

ABSTRACT

Additive manufacturing (AM), particularly vat photopolymerization techniques such as stereolithography (SLA) and digital light processing (DLP), has emerged as a powerful tool for fabricating complex and high-resolution resin-based composite materials. As global industries shift toward more sustainable production paradigms, it is becoming increasingly important to assess the environmental, material, and energy-related impacts of these advanced manufacturing methods. This review article provides a comprehensive examination of the sustainability aspects of resin-based composite production via AM. It focuses on key factors including raw material selection, energy consumption during the printing process, waste management of uncured resins, and challenges associated with the recyclability of thermoset-based systems. Emphasis is placed on the growing use of bio-based resins, natural nanofillers, and hybrid reinforcements that aim to minimize environmental footprints while maintaining or improving functional performance. In addition, the article evaluates recent developments in lifecycle assessment (LCA) approaches, and circular economy strategies such as reusability, design for disassembly, and closed-loop material flows. By synthesizing current research and technological trends, the review identifies both the challenges and opportunities in making photopolymer-based AM more sustainable. It aims to guide researchers, designers, and manufacturers toward the adoption of environmentally responsible practices in the development of next-generation composite materials.

Keywords: Additive Manufacturing, Sustainability, Bio-Based Resins, Lifecycle Assessment (LCA), Circular Design

1. GİRİŞ

Eklemeli imalat (Eİ) olarak da bilinen üç boyutlu baskı teknolojileri, otomotiv, havacılık ve sağlık gibi birçok sektörde hızlı prototipleme ve üretim aracı olarak yaygın şekilde kullanılmaktadır [1]. Özellikle polimer malzemelerin baskısında kayda değer bir artış yaşanmakta, pazar her yıl çift haneli büyüme oranları sergilemektedir [2]. Ancak bu hızlı büyüme, beraberinde ciddi miktarda plastik atığın ortaya çıkmasına yol açmaktadır [3]. Eİ süreçleriyle üretilen plastik parça sayısının artması, kullanım ömrü sonunda atık oluşumunu hızlandırmakta ve çevresel yük oluşturmaktadır. Özellikle, stereolitografi (SLA) ve dijital ışık işleme (DLP) gibi fotopolimer haznesi içerisindeki sıvı reçinenin ışıkla kürlenmesine dayanan vat fotopolimerizasyon tekniklerinde yaygın olarak petrol türevi termoset reçineler kullanılmaktadır. Bu reçineler, kullanım sonrasında kolayca geri dönüştürülemedikleri için plastik kirliliğini artıran bir unsur haline gelmektedir [4]. Bu nedenle, sürdürülebilir malzemelere ve süreçlere geçiş bu alanda büyük önem kazanmıştır.

Sürdürülebilirlik perspektifinden bakıldığında, reçine bazlı Eİ teknolojilerinin iyileştirilmesi için yaşam döngüsünün tüm aşamalarında geliştirici önlemler alınması gerekmektedir. Hammadde seçiminden başlayarak ürünün kullanım ömrü sonundaki bertarafına kadar uzanan bu süreçte, her adım çevresel etkileri azaltma potansiyeli taşımaktadır [5]. Örneğin, biyobazlı veya geri kazanılmış kaynakların hammadde olarak kullanılması, petrole olan bağımlılığı azaltarak karbon ayak izini düşürebilir. Benzer şekilde, baskı sürecinin enerji verimliliğinin artırılması ve üretim sırasında oluşan atıkların en aza indirilmesi önemli hedefler arasındadır. Nihai üründe termoset yapıların oluşması, bu malzemelerin yeniden kullanımı veya geri dönüşümünü güçleştirmektedir; çünkü termoset polimerler yapıları gereği tekrar eritilerek şekillendirilemezler. Bu nedenle, mevcut araştırmalar, baskı sonrası mekanik ya da kimyasal geri dönüşüm yöntemlerinin geliştirilmesine veya baştan itibaren yeniden işlenebilir reçinelerin tasarımına odaklanmaktadır. Bu sürdürülebilir dönüşüm, aynı zamanda döngüsel ekonomi kavramıyla da örtüşmektedir. Döngüsel ekonomi, malzemelerin ömrünü uzatmayı, yeniden kullanımını ve geri dönüşümünü maksimize etmeyi hedefleyen bir yaklaşımdır [6]. Reçine esaslı Eİ'de döngüsel ekonomi uygulamaları; baskı sırasında oluşan artıkların yeniden değerlendirilmesi, sökülebilir tasarım ilkelerinin benimsenmesi ve malzeme akışlarının kapalı döngüler halinde organize edilmesi gibi yöntemleri içermektedir [7]. Bu yaklaşımlar henüz gelişme aşamasında olsa da endüstride artan bir farkındalık söz konusudur.

Bu derleme makalesinde, reçine esaslı vat fotopolimerizasyon tekniklerinde (SLA ve DLP gibi) sürdürülebilirlik konusundaki güncel gelişmeler kapsamlı şekilde ele alınmaktadır. Çalışmanın kalan bölümleri şu şekilde yapılandırılmıştır: Bölüm 2'de çalışmanın literatür tarama yöntemi açıklanmıştır. Bölüm 3'te ise hammadde seçimi (biyobazlı reçineler, doğal nano dolgular, hibrit takviyeler), enerji tüketimi ve baskı verimliliği ile yaşam döngüsü değerlendirmesi (LCA) uygulamaları başlıkları altında detaylı analizler sunulmaktadır. Sonuç bölümünde ise çalışmanın temel bulguları özetlenerek, sürdürülebilir vat fotopolimerizasyon teknolojilerine yönelik öneriler ve gelecekteki araştırma alanları vurgulanmaktadır.

2. YÖNTEM

Bu çalışma, vat fotopolimerizasyon tabanlı reçine sistemlerinde sürdürülebilirlik konusuna odaklanan sistematik bir literatür taramasına dayanmaktadır. Tarama süreci, ilgili literatürün tanımlanması, seçilmesi, bilgi çıkarımı ve tematik olarak sınıflandırılması olmak üzere üç ana aşamadan oluşmaktadır. Uygulanan yöntem, konuya ilişkin güncel, geçerli ve karşılaştırılabilir verilerin derlenmesini amaçlamaktadır.

Literatür taraması aşamasında, ScienceDirect, Web of Science ve Google Scholar gibi yaygın kullanılan uluslararası veri tabanları üzerinden gerçekleştirilmiştir. 2018–2024 yılları arasında yayımlanmış araştırma makaleleri, derlemeler, teknik raporlar ve tezler incelenmiştir. Arama sürecinde hem İngilizce hem Türkçe olmak üzere "SLA/DLP ve sürdürülebilirlik",

"biyo-bazlı fotopolimer", "3D baskı reçinesi geri dönüşümü", "vat fotopolimerizasyon LCA" gibi anahtar kelimeler ve bunların eşdeğer terimleri kullanılmıştır. Arama sonuçlarında elde edilen yayınlar IMRAD (Giriş, Yöntem, Bulgular ve Tartışma) yapısına uygun şekilde değerlendirilmiştir.

Yaklaşık 150 yayına ulaşılan ön tarama sonrasında dört aşamalı bir eleme süreci izlenmiştir: (1) Yinelenen yayınlar elenmiştir. (2) Başlık ve anahtar kelimeler taranarak doğrudan konu dışı olanlar çıkarılmıştır. (3) Ardından özetleri incelenerek ilgisiz ya da yetersiz içerik sunan çalışmalar hariç tutulmuştur. (4) Geriye kalan yayınlar giriş, bulgular ve tartışma bölümleri açısından derinlemesine incelenmiştir. Bu süreç sonunda 50'den fazla nitelikli kaynak belirlenerek derlemeye dahil edilmiştir. Bu çalışmaların amaçları, kapsadıkları mühendislik alanları, kullanılan malzemeler, önerilen sürdürülebilirlik stratejileri ve değerlendirme yöntemleri açısından analiz edilmiştir. Elde edilen bulgular, her başlık altında tablo ve şekillerle desteklenerek karşılaştırmalı bir analiz sunacak şekilde yapılandırılmıştır. Her alt bölüm sonunda elde edilen bulgular özetlenmiş ve sonraki konuyla mantıksal bir geçiş sağlanmıştır.

3. BULGULAR

3.1 Hammadde Seçimi: Sürdürülebilir Reçine Formülasyonları

3.1.1 Biyobazlı Reçine Sistemleri

Eklemeli İmalat (Eİ) kullanılan fotopolimer reçinelerin önemli bir kısmı fosil yakıtlardan türetilen akrilat veya epoksi bazlı oligomer ve monomerlerden oluşmaktadır [4]. Sürdürülebilirlik perspektifinden, bu petrokimyasal kaynakların yenilenebilir biyolojik kaynaklarla ikame edilmesi kritik bir adımdır. Biyobazlı reçineler, karbon kaynağı olarak biyokütleyi kullanmaları nedeniyle üretim aşamasında daha düşük karbon ayak izi bırakabilir ve genellikle son ürünün biyolojik olarak parçalanabilirliğine katkı sağlayabilir. Son yıllarda, bitkisel yağlar, ligno-selülozik biyokütle ve hatta hayvansal atıklardan türetilen kimyasallar kullanılarak fotopolimer reçineler sentezlenmiştir [8].

Bitkisel yağlar, doymamış trigliserit yapıları sayesinde fotopolimer reçine üretimi için uygun fonksiyonel gruplar sağlayabilir. Örneğin soya fasulyesi yağının epoksitlenmesi ve ardından akrilatlanması ile elde edilen akrilatlanmış epoksitlenmiş soya yağı (AESO), yaygın bir biyobazlı reçinedir [9]. Tek başına AESO oldukça yüksek viskoziteye sahip olduğu için, genellikle daha düşük viskoziteli reaktif seyrelticilerle karıştırılarak kullanılmaktadır [10]. Rosa vd., poli(etilen glikol) diakrilat (PEGDA) ile %80 AESO karışımından oluşan bir reçine sistemi geliştirilmiştir [11]. Bu sistem %68.8 gibi yüksek bir karbon içeriğine sahip olmasına rağmen, SLA baskı için uygun viskozite aralığında kalmıştır. Elde edilen numuneler, su emiliminde %93'e varan azalma (şişme testlerinde) göstermiş ve mekanik olarak 4.4 MPa çekme direnci ile %25 kopma uzaması değerlerine ulaşmıştır [11]. Bu değerler, ticari petrokimyasal reçinelere yakın mekanik özellikler sağlanabileceğini gösterir niteliktedir. Bir diğer yenilikçi yaklaşım olarak, bitkisel yağlardan elde edilen monomerlerin dinamik kovalent bağlar içerecek şekilde tasarlanması gösterilebilir. Bu kapsamda Stouten vd., vanilin (odunsu ligninin bir türevi) ile bir yağ asidi türevi kullanılarak imin (Schiff bazı) bağları içeren bir fotopolimer sentezlenmiştir [12]. Vanilin bazlı bu reçine, DLP yöntemiyle başarıyla basılabilmiş ve kürleme sonrası oluşan ağ yapısı, vitrimer özelliği sergileyerek 180°C civarında 5 dakika içerisinde yeniden işlenebilmiştir. Bu özellik, termoset polimerin ısı altında tekrar şekillendirilebilmesi anlamına gelir ve malzemeye adeta termoplastik bir yeniden kullanım imkânı sunmaktadır. Böylece hem biyobazlı hem de tekrar işlenebilir bir reçine geliştirilmiş olmaktadır [12].

Bitkisel yağ türevlerinin yanı sıra lignoselülozik biyokütle türevleride DLP sürecine dahil edilerek sürdürülebilirlik özellikleri geliştirilebilir. Biyokütlenin temel bileşenleri olan selüloz, hemiselüloz ve lignin, fotopolimer reçine formülasyonlarına hem doğrudan dolgu

malzemesi olarak hem de kimyasal türevler şeklinde dahil edilmektedir. Selülozun hidroksil gruplarının metakrilatlanması ile üretilen selüloz metakrilat, UV ile çapraz bağlanabilir bir polimer sağlar ve biyobozunur özellikte ağ oluşturabilir [13, 14]. Laktik asit, kaprolakton gibi biyo-kaynaklı monomerlerden türetilen akrilatların kullanımı da, nihai reçinenin su veya enzimler yardımıyla parçalanabilirliğini sağlamaktadır [15]. Örneğin, kaprolakton (CL) ve trimetilen karbonat (TMC) gibi biyobozunur poliesterlerin akrilat uç gruplarıyla sonlandırılmasıyla hazırlanan reçine sistemleri, SLA ile basıldıktan sonra sulu ortamda hidroliz olarak parçalanabilmektedir [8, 16]. Benzer şekilde, jelatin gibi hayvansal kökenli bir polimerin metakrilat türevleri (örneğin GelMA – jelatin metakrilat), biyobazlı ve biyobozunur bir reçine ağı oluşturarak özellikle doku mühendisliği uygulamalarında kullanılmaktadır [17, 18]. Bu tip malzemeler, baskı sonrasında enzimatik yollarla çevrede parçalanabildikleri için sürdürülebilirlik avantajına sahiptir.

Diğer bir lignoselülozik yapı olan lignin, ahşap ve tarımsal atıklardan bolca elde edilen aromatik bir polimerdir ve karbon bakımından zengindir. Lignin, doğrudan reçine matrisine dolgu olarak katılabileceği gibi kimyasal olarak modifiye edilerek reçinenin yapı taşı haline de getirilebilmektedir [19]. Sutton vd., çalışmasında, ticari SLA yazıcılarda baskılanabilir viskozite ve reaktivite aralığında lignin- türevi fotopolimer reçineler hazırlanmıştır [20]. Modifiye lignin içerikli bu reçineler, ağırlıkça %15'e varan oranda lignin türevi içermektedir. Elde edilen numuneler ticari reçinelere kıyasla 4 kat daha fazla tokluk sergilemiş, baskı kalitesi olarak katmanlar arası kaynaşma, yüzey pürüzsüzlüğü ve şeffaflık açısından başarılı bulunmuştur [20]. Bu sonuç, ligninin uygun kimyasal formlarda fotopolimer reçinelere entegre edilerek hem mekanik performansı iyileştirebileceğini hem de petrokimyasal hammadde ihtiyacını azaltabileceğini göstermektedir. Başka bir çalışmada Wan vd., ligninden elde edilen vanilin ve guaiacol gibi aromatik molekülleri akrilat monomer sentezinde kullanmıştır [21]. Vanilin ve türevleri, hem aromatik sertlik katan yapı taşlarıdır hem de doğal kaynaklıdır. Bu tür biyobazlı reçinelerin en önemli avantajı, fosil kaynaklı akrilatların tamamen elimine edilmesidir. Fakat ligninden türetilen aromatik akrilatlar, biyobazlı olarak değerlendirilmesine rağmen çevresel etkilere dirençli olduklarından biyobozunur değillerdir. Bu nedenle hidrolize olabilen ester bağları gibi yapıların eklenerek yeni yapılar oluşturulabilir [22].

Deniz yosunlarından elde edilen alginat, kitin/chitosan türevleri, doğal kauçuk ve çeşitli bitkisel özler de fotopolimer reçine geliştirmede araştırılmıştır [23-25]. Örneğin kitosan metakrilat veya soya proteini gibi polimerik biyomalzemeler, biyouyumlu ve biyobozunur olmaları sayesinde medikal 3B baskı reçinelerine dahil edilmektedir [26, 27]. Bu maddeler genellikle hidrojel formunda baskı için kullanılıyor olsa da klasik SLA reçinelerine karıştırılarak hibrit yapılar da oluşturulabilir. Biyolojik kaynaklı diğer dikkat çekici bir bileşen, terpen bazlı reçinelerdir. Terpenler (örn. limonen, pinein gibi uçucu yağ bileşenleri) çift bağ içerikleri sayesinde fotopolimerize edilebilir. Literatürde terpen türevli akrilatlar veya vinil eterler kullanılarak düşük toksisiteli reçineler hazırlandığı belirtilmektedir. Terpen bazlı reçineler, petrokimyasal akrilatlara alternatif olarak hoş kokulu ve doğal kaynaktan gelen monomerler sunmaktadır [28-30]. Fakat bunların mekanik dayanım ve kararlılık açısından endüstri standartlarını yakalaması için daha fazla çalışma gerektiği vurgulanmaktadır. Tablo 1'de biyobazlı fotopolimer reçineleri konu alan çalışmalar ve uygulama alanları özetlenmiştir.

Tablo 1. Seçili biyobazlı fotopolimer reçine örnekleri ve özellikleri

Biyokökenli Kaynak	Türetilen Reçine Bileşeni	Özellikler ve Uygulamalar	Kaynak
Soya yağı (bitkisel yağ)	Acrylated epoxidized soybean oil (AESO)	Yüksek biyoiçerik (%60-80); PEGDA ile viskozite ayarı; Selüloz ile takviye edilebilir; Medikal prototiplerde kullanımı	[11]
Atık bitkisel yağ (kızartma yağı)	Atık yağ akrilat (WCO acrylate)	Kullanılmış yağdan elde; Toprak altında biyolojik bozunma göstermiş; Çözgen kullanılmadan sentezlenmiş	[31]
Lignin (odun atığı)	Modifiye lignin oligomer (ör. metakrilatlı lignin)	%15'e kadar lignin içeriği; Ticari SLA reçinesine göre 4 kat tokluk; Yüzey kalitesi yüksek	[20]
Vanilin (lignin türevi)	Dinamik imin bağ içeren reçine (vitrimer)	Tamamen biyobazlı monomerler; 180°C'de yeniden şekillendirilebilir (vitrimer); Sert ve dayanıklı ağ yapısı	[12]
Jelatin (hayvansal atık)	Jelatin metakrilat (GelMA)	Biyouyumlu ve biyobozunur; SLA ve özellikle bioprinting uygulamaları; Enzimatik olarak parçalanabilir	[32, 33]
Terpenler (örn. limonen)	Terpen türevli di-akrilat ve viniller	Düşük toksisiteli, doğal esans içeriği; Kısıtlı mekanik dayanım (esnek yapılar); Düşük koku profili	[30, 34]

Tablo 1'de görüldüğü üzere, farklı kaynaklardan türetilmiş monomer ve oligomerler kullanılarak oldukça yüksek oranda yenilenebilir karbon içeren reçineler elde edilebilmiştir. Bir kısmı (örn. atık yağ ve vanilin bazlı reçineler) aynı zamanda özel işlevsellikler (biyobozunurluk, tekrar işlenebilme) göstererek sürdürülebilirlik açısından çifte kazanım sunmaktadır. Bununla birlikte, bu malzemelerin birçoğunun ticari reçineler kadar yüksek mekanik performans veya işlemsel kolaylık sağlamadığı not edilmiştir. Ayrıca bu yeni biyomalzemelerde yüksek viskozite, düşük tokluk veya yavaş kürlenme gibi sorunlarda görülmektedir. Bu nedenle gelecek çalışmalar, biyobazlı içeriği artırırken baskı performansı ve parça özelliklerini optimize etmeye odaklanmalıdır.

3.1.2 Atık ve geri dönüşüm tabanlı hammaddeler

Sürdürülebilir malzeme geliştirme stratejilerinin bir diğer ayağı, atık materyallerin veya yan ürünlerin değerlendirilmesidir. Hammadde boyutunda ele alındığında, sanayi veya tüketim kaynaklı atıkların fotopolimer reçine sentezinde kullanımı, hem atık azaltımı hem de fosil kaynak kullanımının düşürülmesi anlamına gelmektedir. Literatürde özellikle atık yemeklik yağlar, endüstriyel yan ürünler ve CO2 gibi bileşenlerin reçine üretimine entegre edildiği çalışmalara rastlanmaktadır [35, 36]. Fast-food endüstrisi ve evsel kullanım sonucu ortaya çıkan kullanılmış kızartma yağları, genellikle özel atık olarak bertaraf edilmesi gereken problemli atıklardır. 2020 yılında yapılan bir çalışmada, McDonald's restoranlarından toplanan atık kızartma yağları doğrudan kimyasal modifikasyona tabi tutularak SLA için uygun bir fotopolimer reçineye dönüştürülmüştür [37]. Bu süreçte atık yağ içindeki çift bağlar akrilat grupları ile fonksiyonelleştirilmiş, ortaya çıkan akrilatlı yağ karışımı herhangi bir çözücü kullanılmaksızın DLP yazıcı ile kürlendirilebilir hale getirilmiştir. Elde edilen reçine ile yazdırılan parçaların toprak altında bırakılarak yapılan biyobozunma testlerinde, malzemenin zamanla parçalandığı gözlemlenmiştir. Atık yağlardan elde edilen bu tarz reçineler henüz ticari ölçekte olmasa da, döngüsel ekonomi prensiplerinin 3B baskı malzemelerine uygulanması açısından yol göstericidir.

Diğer yandan karbondioksit (CO2) gazı, iklim değişikliğinin başlıca sorumlularından biri olup endüstriyel atık olarak bolca bulunmaktadır. CO2'nin kimyasal dönüşümlerle polimer yapısına entegre edilmesi, bir yandan gazın zararsız bileşiklerde tutulmasını sağlarken diğer yandan fosil hammaddelerin yerine geçebilecek polimerik yapı taşları üretmektedir [38]. SLA malzemelerinde CO2 kullanımına dair bir araştırmada, CO2'nin poliüretan akrilat yapısında bağlandığı ve böylece reçinenin bir kısmının atmosferik karbon kaynağından geldiği rapor edilmiştir [36]. Bu çalışma, CO2 bazlı segmentler içeren reçinenin baskı ve kullanım performansının da rekabetçi olabildiğini göstermektedir. Henüz sınırlı sayıda çalışma olmakla birlikte, CO2'nin epoksitlerle reaksiyonu sonucu oluşan poli(karbonat) yapılarının akrilatlanarak fotopolimer reçinelere dönüştürülmesi potansiyel bir araştırma alanıdır [39].

Bunun yanında, biyodizel üretimi gibi endüstrilerde yan ürün olarak ortaya çıkan gliserol veya kâğıt endüstrisi atığı lignosülfonatlar gibi maddeler de fotopolimer reçine sentezinde değerlendirilmektedir. Örneğin gliserolün çok fonksiyonlu akrilatlara dönüştürülmesi, çapraz bağ yoğunluğu yüksek ağ yapıları elde etmeye imkan tanır. Literatürde, atık gliserolden üretilen triol akrilatların standart reçine formülasyonlarına katılarak baskı yapılabildiğine dair çalışmalar mevcuttur [40-42]. Bu, hem gliserol atığının azaltılması hem de fosil bazlı akrilatların kısmen ikamesi anlamına gelmektedir.

Özetle, atık ve yan ürünlerin değerlendirilmesi henüz emekleme aşamasında olsa da, çevresel ve ekonomik katkıları nedeniyle popüler bir konu olmaya başlamıştır. Bu yaklaşım, malzeme üretiminin tamamen lineer (hammadde kullan, ürünü yap, atığa bırak) karakterini değiştirerek döngüsel bir akış oluşturmayı hedeflemektedir. Gelecekte, daha fazla sanayi atığının bu şekilde 3B baskı malzemelerine kazandırılması mümkün görünmektedir. Özellikle gıda, tarım ve biyo-yakıt sektörlerinin atıkları bu açıdan zengin bir ham madde potansiyeli sunmaktadır.

3.1.3 Doğal nano takviyeler

Reçine esaslı 3B baskı malzemelerinde mekanik performansı artırmak veya belirli fonksiyonel özellikler kazandırmak için takviye malzemesi kullanımı yaygın bir yaklaşımdır. Sürdürülebilirlik temasında, takviye malzemelerinin seçimi de önem kazanmaktadır. Zira doğal veya geri kazanılmış takviye kullanımı, malzemenin toplam çevresel profilini iyileştirebilir. Doğal nano takviye, yüksek yüzey alanları sayesinde düşük miktarlarda eklenseler bile belirgin etkiler yaratabilirler. Ayrıca, doğal kaynaklı oldukları için üretimleri görece düşük enerji gerektirebilir ve kullanım ömrü sonunda çevreye zararları sınırlı olabilir. Bu kapsamda selüloz ve türevleri, lignin ve doğal lif tozları ve hibrit takviye malzemeleri fotopolimer reçine içerisine dahil edilebilir [43].

Selüloz nano-kristalleri (CNC) ve nano-fibrilleri (CNF), bitkisel liflerden elde edilen, mekanik mukavemeti yüksek ve biyo-uyumlu nano parçacıklardır. Fotopolimer reçinelere selülozik nano- takviye eklemek, özellikle elastik modül ve çekme dayanımı gibi özellikleri geliştirmektedir [44]. CNC ve CNF, yüzeylerinde hidroksil grupları taşıdığından, reçine matrisiyle hidrojen bağı veya kovalent bağ (ön yüzey modifikasyonuyla) kurabilirler. Bu da gerilmelerin etkin taşınmasına olanak vermektedir. Li vd., çalışmasında, CNC takviyesiyle parça dayanımında kayda değer bir artış elde etmesine karşın UV kürlenmesinde ciddi bir yavaşlamayla karşılaşmışlardır [45]. Zira opak dolgu maddeleri genellikle ışık geçirgenliğini azaltıp fotopolimerizasyon derinliğini düşürülmektedirler.

Lignin, modifiye halde reçine yapısına katılabildiği gibi (bkz. Bölüm 3.1.1) doğrudan takviye malzemesi olarak fotopolimer reçine içerisine de dahil edilebilir. Toz halinde lignin veya odun talaşı, fotopolimer reçineye karıştırıldığında, nihai parçada kısmen biyobozunur bir faz yaratır ve mekanik dayanımı artırır. Arias-Ferreiro vd., akrilik bazlı bir reçineye %4 ağırlığa kadar ham lignin tozu katılmış ve DLP baskı ile örnekler üretilmiştir [46]. Lignin dolgusunun, beklenenin aksine, parçaların kırılganlığını azaltıp daha tok bir davranış verdiği görülmüştür.

Bunun sebebi, ligninin amorf bir polimer olarak baskı sonrasında matriste mikro-alevlenme yaparak çatlak ilerlemesini zorlaştırması olabilir. Ayrıca lignin, UV ışığını bir miktar soğurur; bu durum düşük oranlarda kontrol edilebilirken yüksek dolgu yüklerinde baskı başarısını olumsuz etkileyebilir. Bu nedenle tipik olarak %1-5 aralığı, doğal toz dolgular için pratik üst sınırlar olarak bildirilmektedir. Diğer doğal kaynaklı dolgulardan bazıları: öğütülmüş ağaç kabuğu, pirinç kabuğu külü, ceviz kabuğu tozu, kil ve nanokil (montmorillonit) gibi mineraller de literatürde test edilmiştir [47, 48]. Kil mineralleri doğal olmasına karşın biyobozunur değildir; ancak çok bol ve düşük maliyetli olmaları, ayrıca doğada hali hazırda var olmaları nedeniyle sürdürülebilirlik açısından nötr sayılabilirler. Nanokil katkısı, reçinenin termal dayanımını ve bariyer özelliklerini artırabilir, ancak optik geçirgenliği ciddi ölçüde düşürür. Bu nedenle, eğer kullanılacaksa genellikle ışık geçirgenliğinin çok kritik olmadığı koyu renkli reçinelerde veya yüzeysel kürlemelerde tercih edilir [49] .

Ayrıca birden fazla tür takviye malzemenin veya takviye metodunun bir arada kullanılmasıyla elde edilen hibrit takviyelerle de sürdürülebilir özellikler elde edilebilir.

Örneğin, hem organik (doğal lif) hem inorganik (seramik nano toz) takviyenin birlikte kullanımı, ya da hem partikül hem fiber takviyesinin aynı anda yapılması hibrit yaklaşımlar olarak görülebilir. Literatürde, örneğin bir reçineye hem selüloz nano-lif hem de hidroksiapatit nanopartikül eklenerek biyomedikal amaçlı kompozit çıktılar elde edilmiştir [50] . Bu iki takviyenin birlikte kullanıldığında, selüloz mekanik tokluk sağlarken hidroksiapatit kemiğe benzer bir sertlik ve biyoaktivite kazandırmıştır. Hibrit takviyeler, tekil bir dolgunun yaratabileceği olumsuzlukları dengeleyebilir; örneğin tek başına çok kırılgan hale getiren sert bir dolgu, yanına eklenecek ikinci bir sünek faz ile dengelenebilir [51]. Bir diğer hibrit yaklaşımı da polimer-polimer karışımların kullanılmasıdır. Örneğin, fotopolimer reçineye belirli oranda termoplastik bir polimer çözeltisi eklemek, baskı sonrası malzemede iki fazlı bir yapı oluşturur. Bu yapı, bir faz termoplastik elyaflar, diğer faz termoset matris olacak şekildedir. Bu yöntem, reçine içerisinde in-situ fiber oluşturma olarak da bilinmektedir. Ramezanpour vd., poliüretan esaslı esnek bir polimer, sıvı akrilat reçineye çözünmüş halde eklenmiş ve baskı sırasında bu polimer ayrışarak ayrı bir faz oluşturmuştur [52]. Sonuçta oluşan parçalar, daha yüksek darbe dayanımına sahip hibrit bir yapıya kavuşmuştur.

Genel olarak, sürdürülebilirlik açısından malzemeye doğal takviyeler eklemek dikkat gerektiren zorlu bir süreçtir. Düzgün tasarlandığında hem performansı hem çevresel profili iyileştirirken, kötü tasarım halinde baskı başarısını düşürebilir veya geri dönüşümünü zorlaştırabilir. Bu nedenle, optimal takviye tipi ve miktarının belirlenmesi önem taşmaktadır. Literatürdeki bulgular, %1-10 aralığındaki doğal nano-takviyeli ilavelerinin genellikle olumlu mekanik katkı sağladığını, ancak daha yüksek yüklemelerin ışık soğurma ve viskozite artışı nedeniyle problem oluşturabildiğini ortaya koymaktadır [53]. Hibrit takviyelerde ise sinerjik etkilerden bahsedilse de, sistem karmaşıklığının arttığı ve her bileşenin uyumunun ayrı optimizasyon gerektirdiği unutulmamalıdır.

3.2 Enerji Tüketimi ve Baskı Verimliliği

Eklemeli imalat teknolojilerinin çevresel etkilerinden biri de enerji tüketimi kaynaklı karbon emisyonlarıdır. Bir üretim yönteminin sürdürülebilir olması için sadece malzemesinin değil, işlem adımlarının da enerji açısından verimli olması beklenir [5]. SLA ve DLP gibi reçine bazlı baskı teknikleri, enerji tüketimi profili bakımından diğer 3B baskı yöntemlerinden bazı farklılıklar gösterir. Bu bölümde, vat fotopolimerizasyon süreçlerinin enerji kullanımı ve verimliliği ele alınmakta; literatürdeki değerlendirmeler ve iyileştirme yöntemleri incelenmektedir.

Fotopolimerizasyon tabanlı yazıcılarda temel enerji gereksinimi, ışık kaynağı (lazer veya projektör) ve hareket mekanizmalarının elektrik tüketiminden gelir. SLA'da genellikle bir UV lazer tarama yaparak reçineyi kürler; DLP'de ise bir projektör tek seferde tüm katmanı

aydınlatarak kürleme yapar [54]. Bu iki alt yöntem arasında enerji kullanım deseni farklı olabilir. DLP, katman bazında alan projeksiyonu yaptığından, özellikle çoklu parçaların paralel üretiminde zaman ve enerji tasarrufu sağlayabilir. SLA ise lazerin tüm alanı taraması gerektiğinden, büyük yüzeyli katmanlarda daha uzun süre ışık kullanır. Bununla birlikte, modern SLA sistemleri galvanometre aynalar ile çok hızlı tarama yapabilmekte ve tek parça üretiminde DLP ile benzer sürelerde işlemi tamamlayabilmektedir. Enerji tüketimini belirleyen faktörlerin başında baskı süresi gelir: daha kısa sürede biten bir baskı, toplamda daha az enerji tüketecektir [8]. Bu nedenle bir yöntem daha hızlı ise, aynı parça için daha az enerji harcama potansiyeline sahiptir.

Yapılan bir karşılaştırmalı çalışmada, aynı boyut ve geometrilerde parçalar FDM (eriyik yığma) ve SLA ile üretilmiş; sonuçta SLA'nın daha yüksek yüzey kalitesi ve hassasiyet sağlamakla birlikte, enerji verimliliği açısından FDM'nin biraz gerisinde kaldığı rapor edilmiştir [55]. Bunun bir nedeni, FDM'de malzeme ekstrüzyonu sırasında harcanan enerjinin büyük bölümünün ısıtma için kullanılması fakat işlemin nispeten kısa sürmesidir. SLA'da ise lazerin sürekli çalışması ve reçine tankının motorlarının hareketi, uzun süreli düşük-orta güç tüketimi yaratır. Söz konusu çalışmada FDM, parça başına yaklaşık %60 daha az enerji tüketerek üretimi tamamlamıştır. Ayrıca FDM'de kullanılan malzemelerin (filament) üretimindeki enerji ve çevresel yük de değerlendirildiğinde, eğer biyobazlı PLA kullanılırsa çevresel açıdan SLA'ya kıyasla avantajlı bulunmuştur [55]. SLA sürecinin bir diğer enerji girdisi de işlem sonrası adımlardır: Basılan parçaların genellikle izopropil alkol (IPA) gibi çözücülerle yıkanması ve son kürleme ünitesinde UV lambalarıyla sertleştirilmesi gerekir [56]. Bu adımlar da ilave enerji ve kaynak tüketimine neden olur. Öte yandan FDM parçaları için genellikle böyle bir ek işlem gerekmez. Bu karşılaştırma, SLA teknolojisinin mükemmel yüzey ve detay avantajlarının bir bedeli olarak, enerji ve çevresel maliyet anlamında daha dikkatli yönetilmesi gerektiğini ortaya koymaktadır. Bununla birlikte, farklı çalışmalar farklı sonuçlar da verebilmektedir. Başka bir LCA çalışmasında, bir plastik laboratuvar ekipmanı hem SLA hem de FDM ile üretilip çevresel etkileri karşılaştırılmıştır [57]. Çalışmaya göre UV reçine ile üretilen parçanın birden çok etki kategorisinde daha düşük çevresel yüke sahip olduğu rapor edilmiştir. Bu sonuç, baskı süresi ve malzeme verimliliği ile açıklanmıştır: SLA yöntemi, aynı parçayı FDM'den daha hızlı üretmiş (450 dk vs 550 dk) ve FDM'deki yüksek sıcaklık gereksinimi nedeniyle birim zaman başına daha düşük güç çekmiştir. Ayrıca SLA, baskı esnasında destek yapıları dahil malzemenin %95'inden fazlasını kullanmış, çok az atık bırakmıştır; oysa FDM'de filaman değişimi, başlatma/bitirme sırasında oluşan ufak atıklar, brim/raft gibi ek yapılar bir miktar israf yaratmıştır [57].

Enerji tüketimini azaltmanın bir diğer yolu, baskı süresini veya makinenin aktif çalışma zamanını azaltmaktır. Katman kalınlığı, doluluk oranı, baskı hızı, destek yapısı gibi parametreler hem baskının başarı ve kalitesini hem de enerji tüketimini etkiler [58]. Araştırmalar, örneğin katman kalınlığının artırılmasıyla enerji tüketiminin önemli ölçüde düşebileceğini göstermiştir, çünkü daha kalın katman demek daha az katman sayısı ve dolayısıyla daha kısa toplam kürleme süresi demektir. Yapılan bir çalışmada optimum baskı parametrelerinin seçilmesiyle enerji tüketiminin %48 ila %72 oranında azaltılabileceği belirtilmektedir [59]. Bununla birlikte, çok kalın katman kullanımı baskı çözünürlüğünü düşüreceği için, bir denge gözetilmelidir. Benzer şekilde, birden fazla parçanın aynı anda basılması, SLA/DLP'nin alan-kürleme avantajı sayesinde enerji tasarrufu sağlar; çünkü tek seferde daha fazla ürün alınır. Bu, özellikle DLP için geçerlidir: Aynı enerjiyle bir seferde platformdaki tüm parçalar kürlendiğinden, parçaları tek tek basmaya kıyasla toplam enerji/parça düşer. Bu nedenle platformu tam doldurarak baskı yapmak, enerji verimliliğini arttırır [59]. Baskı parametresi optimizasyonuna ilişkin bir çalışma Tablo 2'de özetlenmiştir.

Bu tabloda, enerji tüketimini etkileyen belli başlı parametreler ve bunların etkileri listelenmiştir.

Tablo 2'den görüleceği üzere, SLA/DLP süreçlerinde parametre optimizasyonu ve donanım seçimi enerji tüketiminde belirleyici olmaktadır. Özellikle vat fotopolimerizasyonda ön ısıtma gerekmemesi önemli bir avantajdır; bir çalışma, FDM teknolojisinde enerji tüketiminin önemli bir kısmının tabla/nozül ısıtmasına gittiğini ve SLA baskının benzer boyuttaki bir parçayı yaklaşık 100 dakika daha kısa sürede tamamladığını belirtilmiştir [57]. Bu da SLA'nın kendine özgü bir verimlilik potansiyeli olduğunu gösterir.

Diğer yandan, Baskı sürecini hızlandırarak enerji verimliliğini artırmak amacıyla geliştirilen yeni tekniklerden biri sürekli DLP veya CLIP (Continuous Liquid Interface Production) teknolojisidir [60]. Bu teknikte, katmanlar arası bekleme ortadan kaldırılarak reçine sürekli bir akış halinde katılaştırılır. CLIP teknolojisi, kesintisiz oksijen geçirgen bir pencere kullanarak reçinenin sürekli yükselmesine olanak tanır. Hız arttıkça, enerji tüketimi de aynı oranda düşmeyebilir ancak birim hacim başına harcanan enerji azalır. CLIP teknolojisinin geleneksel DLP'ye kıyasla 25 ila 100 kat hızlanma sağladığı belirtilmektedir [61].

Enerji tüketimi konusu sürdürülebilirlik değerlendirmelerinde kritik bir bileşendir ve Eİ teknikleri arasında farklılıklar gösterebilir. SLA ve DLP gibi reçine bazlı yöntemler, doğru koşullarda makul enerji kullanımına sahip olabilir ancak parametre seçimi ve cihaz teknolojisi bunu belirler. Bu nedenle birim ürün başına enerji tüketimi azaltan daha hızlı ve verimli baskı yöntemlerine doğru bir eğilim görülmektedir.

Tablo 2: Vat Fotopolimerizasyon Baskılarında Enerji Tüketimini Etkileyen Parametreler ve Etkileri

Parametre	Enerjiye Etkisi	Açıklama
Katman Kalınlığı	Kalın katman **Daha az enerji** (kısa süre)	Çok ince katman yüksek çözünürlük sağlar ancak katman sayısını artırarak baskı süresini uzatır. Orta kalınlıklar verimlilik için tercih edilir.
Baskı Hızı	Yüksek hız **Daha az enerji** (kısa süre)	Mümkün olan en yüksek hızda kürleme yapmak süreyi kısaltır. Lazer gücü/projeksiyon süresi ayarlanarak optimum değer bulunur.
Destek Yapısı	Az destek **Daha az enerji** (az malzeme)	Akıllı yerleşim ve açı optimizasyonuyla destekler minimize edilirse hem malzeme israfı hem de bunların basılma süresi azalır.
Parça Sayısı	Çoklu parça → **Birim başına daha az enerji**	DLP'de bir katmanda ne kadar çok parça varsa toplam verim o kadar artar. SLA'da da art arda yerine birlikte basmak lazerin ısınma/soğuma döngülerini azaltır.
Işık Kaynağı Türü	LED **Daha az enerji**	Yeni nesil LED tabanlı sistemler daha az elektrikle aynı işi yapar. Lazerlerde de diyot lazerler verimlidir.
Ön Isıtma Gereksinimi	Yok **Daha az enerji**	FDM'de tabla ve nozül ısıtması önemli enerji tüketir. SLA'da genelde ısıtma yoktur, sadece ortam sıcaklığı yeterlidir. Bu durum SLA lehine bir avantajdır.

3.4 Sürdürülebilir Kompozitlerin Yaşam Döngüsü Değerlendirmesi

Bir ürün veya sürecin çevresel sürdürülebilirliğini bütüncül olarak anlamanın en bilimsel yollarından biri Yaşam Döngüsü Değerlendirmesi (Life Cycle Assessment, LCA) yapmaktır. YDD, ham madde çıkarımından başlayarak ürünün üretimi, dağıtımı, kullanımı ve ömrü sonundaki bertarafına kadar tüm aşamalarda meydana gelen çevresel etkileri nicel olarak hesaplar [57]. 3B baskı teknolojileri için de son yıllarda çeşitli YDD çalışmaları yapılmış ve geleneksel üretim yöntemleriyle karşılaştırmaları, ayrıca farklı 3B baskı teknolojilerinin kendi aralarındaki kıyaslamaları literatürde yer almıştır [62].

SLA ve DLP süreçlerinin YDD analizleri, bu teknolojilerin enerji ve malzeme tüketimi, atık oluşumu ve sarf malzemeleri gibi yönlerini nicelleştirmiştir. Örneğin, Mele vd., masaüstü SLA yazıcı ile bir plastik parçanın üretimini beşikten kapıya (cradle- to-gate) yani ham maddeden ürün çıkışına kadar analiz etmiştir [63]. Bu analizde reçinenin üretimi, yazıcı elektriği, reçine nakliyesi, destek malzemesi ve temizleme kimyasalları dahil edilmiştir. Sonuçlar, çevresel etki kategorilerinin büyük kısmında en önemli payın reçine üretiminden ve baskı esnasındaki elektrik tüketiminden geldiğini göstermiştir. Örneğin küresel ısınma potansiyeli (CO_2 eşdeğeri salım) açısından, baskı için kullanılan elektriğin kaynağı kritik bir faktördür. Eğer şebeke elektriği fosil yakıtlardan geliyorsa, baskının karbon ayak izi yükselmektedir. Aynı çalışma, destek yapısı miktarının ve baskı süresinin de çevresel etkileri anlamlı şekilde değiştirdiğini vurgulamıştır [63]. Modelde fonksiyonel birim olarak "bir adet basılı parça" alındığından, parça kütlesinin küçük değişimleri bile etki hesaplarını değiştirebilmektedir.

Birkaç YDD çalışması, geleneksel imalat ile 3B baskıyı karşılaştırmıştır. Örneğin bir senaryoda belirli sayıda ürünün enjeksiyon kalıplama vs. 3B baskı ile üretilmesinin çevresel etkileri incelenmiştir [64-66]. Sonuçlar, düşük üretim adetlerinde kalıp üretimi gibi öncül işlemler gerektirmeyen 3B baskının, yüksek adetli üretimlerde ise geleneksel yöntemlerin daha çevreci olduğu görülmüştür. Yani, özelleştirme ve düşük hacimli üretimde 3B baskı sürdürülebilir bir alternatif olabilir, ama seri üretimde hala dezavantajlı kalabilir. Bu, sürdürülebilirlik tartışmasının sadece malzeme bazında değil, üretim stratejisi bazında da yapılması gerektiğini gösterir. Ulkir farklı 3B baskı malzemelerinin aynı üründeki ydd etkilerini incelemiştir [57]. Aynı ürün ABS, PLA, PETG filamentlerle FDM'de ve UV kürlenen bir reçineyle SLA'da üretilmiş; ham madde çıkarımı, imalat ve geri dönüşüm aşamaları değerlendirilmiştir. İlginç şekilde, bu çalışmada UV reçine malzemesi çevresel açıdan en iyi performansı gösteren malzeme olarak rapor edilmiştir. ABS ise en kötü olarak çıkmıştır. PLA ve PETG ise arada değerlerdedir. Bu sonuca detaylı bakıldığında, UV reçinenin baskı esnasında daha az atık ve enerji tüketmesi, ayrıca parçanın daha hafif olması nedeniyle taşımada avantaj sağlaması gibi etkenlerin rol oynadığı anlaşılmıştır. PLA her ne kadar biyopolimer olsa da, üretimindeki enerji yoğunluğu ve belki senaryoda tam kompostlanmadığı varsayımı gibi nedenlerle UV reçineden daha yüksek etki vermiş olabilir. Bu bulgu, biyobazlı olan malzemenin daha çevreci olduğu algısını yıkmaktadır. Sürdürülebilirlik açısından her bir malzeme ve süreç kombinasyonu ayrı ayrı sayısal analiz gerektirmektedir.

YDD, sadece küresel ısınma etkisi değil, aynı zamanda toksisite, asidifikasyon, ötrofikasyon, ozon tabakası incelmesi gibi bir dizi etki kategorisinde sonuçlar üretmektedir. Örneğin, SLA reçinelerinde kullanılan fotobaşlatıcılar ve akrilat monomerler üretimleri sırasında ve atık olduklarında toksik etki kategorilerinde yüksek skorlar alabilir. FDM'de kullanılan bazı plastikler (ABS gibi) ise üretimde uçucu organik bileşik salımı ve petrol türevi olmaları nedeniyle ozon ve ekotoksisite kategorilerinde kötü performans gösterebilir. Genel olarak, YDD çalışmalarının önerisi, malzeme ve süreç optimizasyonunun birlikte ele alınmasıdır. Örneğin, eğer SLA prosesi kullanılıyorsa, mutlaka yenilenebilir enerji ile

beslenmesi, atık reçinenin uygun şekilde bertarafı ve malzeme verimliliğinin maksimize edilmesi gerektiği vurgulanmaktadır.

Ayrıca döngüsel ekonomi uygulamalarının (ör. yeniden kullanım, geri dönüşüm) fotopolimer reçinenin YDD sonuçlarına etkisi de incelenmiştir [67]. Bir YDD senaryosunda, SLA ile basılan bir ürünün kullanım ömrü sonunda yakılması, gömülmesi veya geri dönüştürülmesi durumları karşılaştırılmıştır. Eğer malzeme geri dönüştürülebilirse (örneğin hipotetik bir vitrimer ile), yeni malzeme üretimine gerek kalmayacağı için ham madde aşamasındaki etkiler yarı yarıya azalabilmektedir. Yakma senaryosu, fosil yakıtlı enerji üretimini ikame ettiği varsayıldığında orta karar bir fayda sağlamıştır. Gömülme ise malzeme potansiyelinin tamamen yitimi ve metan gibi emisyonlar nedeniyle en kötü durum olarak saptanmıştır [63]. Bu tip analizler, henüz teori düzeyinde kalsa da, gelecekte eğer fotopolimer malzemeler geri dönüştürülebilir hale gelirse YDD'lerinin ciddi oranda iyileşeceğine işaret etmektedir [62]. Bu, AR-GE çalışmalarının yönelmesi gereken kritik hedeflerden biridir.

4. SONUÇ

Vat fotopolimerizasyon esaslı 3B baskı teknolojilerinde sürdürülebilirlik alanında son yıllarda önemli ilerlemeler kaydedilmiştir. Bu derleme çalışması kapsamında incelenen literatür, yaşam döngüsünün her aşamasında iyileştirme çabalarının sürdüğünü ortaya koymaktadır. Hammadde seçiminde, yenilenebilir ve biyobazlı reçine bileşenleri geliştirme çalışmaları sayesinde petrokimyasal bağımlılık azalmakta ve potansiyel olarak karbon ayak izi düşmektedir. Lignin, bitkisel yağlar, atık biyomalzemeler gibi kaynaklardan türetilen yeni fotopolimer reçineler, laboratuvar ölçeğinde başarılı sonuçlar vermiştir. Bu malzemeler, ticari muadillerine yakın mekanik özellikler sergilemeye başlamış, hatta bazı durumlarda (örn. modifiye lignin içerikli reçinelerde) tokluk gibi özelliklerde üstün performans elde edilmiştir . Biyobazlı içerik artışı genel bir trend olup, halihazırda pazarda "bitki bazlı" reçine seçenekleri belirmeye başlamıştır.

Enerji tüketimi ve verimlilik boyutunda, baskı ekipmanları ve süreç parametreleri optimize edilerek birim parça başına düşen enerji ihtiyacı azaltılmaktadır. DLP ve benzeri teknolojilerle baskı hızlarının yükselmesi, LED tabanlı ışık kaynaklarının benimsenmesi ve bir platformda çoklu parça üretiminin yaygınlaşması, aynı üretimin geleneksel yöntemlere kıyasla daha az enerjiyle yapılabileceğini göstermektedir .

Atık yönetimi ve geri dönüşüm konusunda, fotopolimerlerin geleneksel dezavantajını aşmaya yönelik yaratıcı çözümler üretilmektedir. Reçine atıklarının tamamen kürlendikten sonra diğer plastik atıklarla birlikte kullanılabilmesi (örneğin öğütülerek dolgu yapılması) pratik bir kısa vadeli çözümdür ve bazı durumlarda uygulanmıştır. Uzun vadede ise termoset malzemelerin geri dönüşümünü mümkün kılan vitrimer benzeri akıllı reçineler, oyun değiştirici niteliktedir. Bu çalışmada aktarılan örneklerden vanilin-tabanlı dinamik ağ yapısı, bu yaklaşımın uygulanabilirliğini kanıtlamıştır. Henüz bu tür malzemelerin piyasada yer edinmesi zaman alacak olsa da büyük kimya şirketlerinin de bu trende yönelmesiyle fotopolimer sektöründe "geri dönüştürülebilir termoset" kavramı yerleşmeye başlayacaktır. Böylelikle, SLA/DLP ile üretilen parçaların kullanım ömrü sonunda da değerli kalması sağlanabilecektir.

Yaşam döngüsü değerlendirmeleri, sürdürülebilirlik stratejilerinin etkinliğini ölçme ve karşılaştırma imkânı sunmuştur. 3B baskının geleneksel üretime kıyasla çevresel avantajları olduğu pek çok çalışmada gösterilmiştir, özellikle özelleştirme ve az adetli üretimde israfı önlemesi bakımından . Ancak yüksek hacimli üretimlerde 3B baskının enerji tüketimi ve malzeme verimliliği halen sorgulanmaktadır. Bu derlemede ele alınan YDD çalışmalarından anlaşıldığı üzere, 3B baskının sürdürülebilirlik performansı, kullanılan malzeme, enerji altyapısı ve üretim stratejisi ile doğrudan ilişkilidir. Dolayısıyla, en iyi senaryoda bile sürekli izleme ve iyileştirme gereklidir. Gelecekte, YDD sonuçlarına dayanarak otomatik optimizasyon yapan "yeşil üretim" yazılımları gündeme gelebilir; örneğin bir parça

basılmadan önce yazılım, onu hangi cihazda/hangi malzemeyle basmanın en az etkiyi yaratacağını hesaplayabilir.

Sonuç olarak, reçine esaslı SLA ve DLP teknolojilerinde sürdürülebilirlik perspektifleri giderek çeşitlenmekte ve güçlenmektedir. Henüz çözülmesi gereken teknik ve lojistik sorunlar olsa da (örneğin termosetlerin tam ölçekli geri dönüşümünün sağlanması veya biyobazlı reçinelerin endüstri standardı mekanik özelliklere ulaşması gibi), mevcut eğilimler bu sorunların aşılabilir olduğunu göstermektedir. Entegre yaklaşımların devreye girmesiyle – yani malzeme, süreç ve iş modelinin birlikte dönüştürülmesiyle – vat fotopolimerizasyon teknikleri önümüzdeki on yılda çok daha düşük çevresel etkiyle çalışabilir hale gelecektir.

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MEX/M YÖNTEMİYLE ÜRETİLEN METAL PARÇALARDA BASKI YÖNELİMİ VE ISIL İŞLEM KOMBİNASYONUNUN YÜZEY KALİTESİNE ETKİSİ: LİTERATÜR İNCELEMESİ

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ÖZET

Metal Malzemelerin Ekstrüzyonu (MEX/M), metal tozu ve bağlayıcıdan oluşan filamentlerin katmanlar halinde biriktirilmesi ve ardından ısıl işlemle nihai metal parçaların elde edilmesi esasına dayanan ekonomik ve erişilebilir yeni bir eklemeli imalat yöntemidir. Özellikle 316L ve 17-4 PH paslanmaz çelikler gibi malzemelerle yapılan uygulamalarda, düşük yatırım maliyeti ve basit sistem yapısı sayesinde MEX/M yöntemi öne çıkmaktadır. Ancak sürecin doğası gereği, katman geçişleri, sinterleme sonrası meydana gelen çekmeler ve yüzeyde oluşabilecek mikroyapısal kusurlar nedeniyle yüzey kalitesi diğer metal üretim tekniklerine kıyasla sınırlı kalabilmektedir. Bu çalışmada, metal MEX/M yöntemiyle üretilen parçaların yüzey kalitesini etkileyen en önemli iki proses parametresi olan baskı yönelimi ve sinterleme koşulları (sıcaklık, süre, atmosfer) literatür ışığında değerlendirilmiştir. Farklı çalışmalarda raporlanan bulgular, yüzey pürüzlülüğü göstergeleri dikkate alınarak karşılaştırılmış ve sinterleme parametrelerinin yüzey pürüzlülüğüne nasıl katkı sağladığı incelenmiştir. İncelemelerde, dikey yönde basılan parçaların daha düşük yüzey pürüzlülüğüne sahip olduğu, buna karşın yatay baskıda katman yapılarının etkisi nedeniyle pürüzlülüğün belirgin biçimde arttığı gözlemlenmiştir. Buna ek olarak, sinterleme sonrası geometrik deformasyonlar, anizotropik çekme oranları ve yüzeyde kalan bağlayıcı kalıntıları gibi yüzey kalitesini etkileyen diğer faktörler literatürde değerlendirilmiş; destek yapılarının tasarımının bu doğrultuda nasıl şekillendirilmesi gerektiğine dair bulgular özetlenmiştir. Bu literatür incelemesi, MEX/M yöntemiyle üretilen metal parçaların yüzey kalitesini iyileştirmeye yönelik araştırmalar için bir temel oluşturmayı ve baskı/sinterleme parametrelerinin birbiriyle etkileşimini anlamlandırmayı amaçlamaktadır.

Anahtar Kelimeler: Eklemeli İmalat, MEX/M, Metal Ekstrüzyon, Yüzey Pürüzlülüğü, Sinterleme, Bağlayıcı Giderme

EFFECT OF PRINTING ORIENTATION AND HEAT TREATMENT COMBINATION ON SURFACE QUALITY IN MATERIAL EXTRUSION ADDITIVE MANUFACTURING OF METALS (MEX/M): A LITERATURE REVIEW

ABSTRACT

Metal Extrusion Additive Manufacturing (MEX/M) is an economical and accessible additive manufacturing method based on layering filaments consisting of metal powder and binder, followed by heat treatment processes to obtain the final metal parts. The MEX/M method stands out due to its low investment cost and simple system structure, especially in applications with stainless steels such as 316L and 17-4 PH. However, due to the nature of the process, surface quality can be limited compared to other metal production techniques due to interlayer transitions, shrinkage after sintering and microstructural defects on the surface. In this study, the two most important process parameters affecting the surface quality of the parts produced with the metal MEX/M method, namely the printing orientation and sintering conditions (temperature, time, atmosphere), were evaluated in the light of literature. The findings reported in different studies were compared by considering the surface roughness indicators and how the sintering parameters contribute to the surface roughness. In the studies, it was observed that the parts printed in the vertical direction exhibited lower surface roughness, but the roughness increased significantly due to the stepping effect in the horizontal direction. While the density increases with the increase of sintering temperature and time, selecting the appropriate atmosphere (especially in hydrogen-containing environments) reduces the formation of oxides on the surface and improves surface integrity. In addition, other factors affecting the surface quality, such as post-sintering geometric deformations, anisotropic shrinkage rates and binder residues remaining on the surface, were evaluated in the literature; findings on how the design of support structures should be shaped in this direction were summarized. This literature review aims to form the basis for research on improving the surface quality of metal parts produced with the MEX method and to make sense of the interaction between printing-sintering parameters.

Keywords: Additive Manufacturing, MEX/M, Metal extrusion, Surface Roughness, Sintering, Debinding

1. GİRİŞ

Eklemeli İmalat (Eİ), 1990'larda 3B bileşenlerin katman katman üretilmesiyle ortaya çıkan ve geleneksel eksiltici imalatın aksine malzemenin biriktirilmesi prensibine dayanan bir üretim yöntemidir. Teknolojideki gelişmeler ve özellikle FDM (Ergiyik Biriktirmeli Modelleme) patentinin 2009'da sona ermesiyle Eİ yöntemleri hızla yaygınlaşmış; prototipleme amaçlı kullanımın ötesine geçerek standart üretim proseslerine dönüşmeye başlamıştır. Eİ, karmaşık geometrilere sahip nesnelerin hızlı üretimi, tasarım özgürlüğü, malzeme israfının azalması ve özelleştirilmiş üretim imkânı gibi avantajları sayesinde imalat paradigmalarını değiştirmektedir. Son yıllarda plastikten metale, seramiğe kadar birçok malzeme için eklemeli imalat teknikleri geliştirilmiştir.

Metal Eklemeli İmalat yöntemleri, toz yatağı tabanlı veya doğrudan enerji girdili sistemler kullanarak karmaşık metal parçaları yüksek doğrulukla üretebilmektedir. Yaygın metal Eİ yöntemleri arasında lazerle veya elektron ışını ile tozların eritildiği SLM (Seçici Lazer Ergitme) ve EBM (Elektron Işını Ergitme), doğrudan enerji biriktirmeli imalat (DED) ve bağlayıcı püskürtme gibi teknikler sayılabilr. Bu yöntemler başarılı sonuçlar verse de, yüksek donanım ve işletim maliyetleri, karmaşık bakım gereklilikleri ve güvenlik sınırlamaları içermektedir . Örneğin, SLM yöntemi günümüzde en yaygın metal eklemeli imalat tekniği olsa da yüksek maliyetli bir altyapı ve kontrollü bir ortam gerektirmektedir.

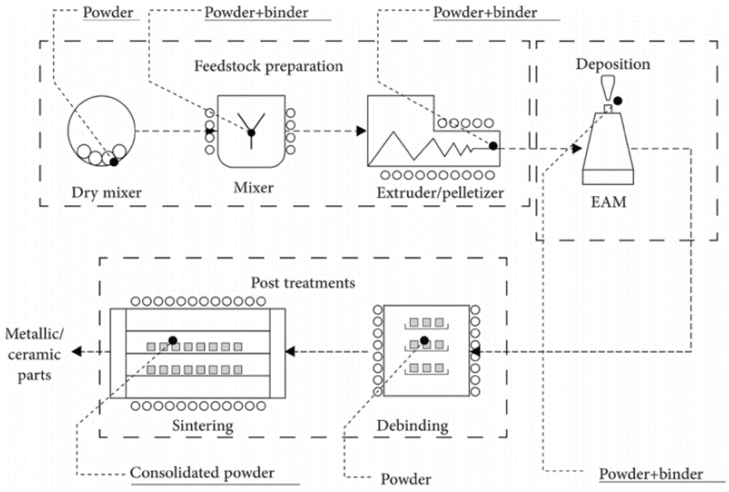
Bu bağlamda, son dönemde Metallerin Malzeme Ekstrüzyonu İle Eklemeli İmalatı (MEX/M) yöntemi yenilikçi yönü ile çekmektedir. MEX/M, metal tozlarının polimer bir bağlayıcı ile harmanlanmasıyla elde edilen filamentlerin, FDM'ye benzer bir şekilde eritilerek üst üste katmanlar halinde biriktirilmesine dayanmaktadır. Yazıcıdan alınan "yeşil parça", daha sonra bağlayıcının uzaklaştırılması (debinding) ve sinterleme adımlarından geçirilerek tamamen metal bir parçaya dönüştürülür. Bu süreç geleneksel Metal Enjeksiyon Kalıplama (MIM) prosesine benzerlik göstermekte olup, enjeksiyon yerine 3B baskı ile şekillendirme yapılmasıyla ayrılmaktadır (Suwanpreecha ve Manonukul, 2022). MEX/M yönteminin en önemli avantajı, toz yatağı kullanan lazer veya elektron demetli sistemlere göre çok daha düşük makine ve malzeme maliyeti ile çalışabilmesidir. Basit ve güvenli çalışma prensibi sayesinde daha küçük ölçekli işletmelerde ve araştırma laboratuvarlarında da metal baskı yapma imkânı sunmaktadır. Nitekim 2015'ten bu yana MEX/M ile ilgili akademik yayınların hızla artış göstermesi, yöntemin sahip olduğu potansiyelin bir göstergesidir (Suwanpreecha ve Manonukul, 2022). Havacılık, tıp, kalıpçılık ve makine imalatı gibi farklı alanlarda MEX/M teknolojisinin kullanımı giderek yaygınlaşmaktadır.

Bu çalışmada MEX/M yöntemiyle metal parça üretilmesi sürecinde yüzey kalitesini belirleyen temel değişkenlerden baskı yönelimi ve sinterleme parametreleri ele alınmıştır. Literatürdeki çalışmalar ışığında, farklı baskı yönlerinde üretilen parçaların yüzey pürüzlülük değerleri karşılaştırılmış ve sinterleme sıcaklığı, süresi ile atmosfer koşullarının yüzey pürüzlülüğü ve bütünlüğüne etkisi incelenmiştir. Ayrıca tartışma bölümünde, destek yapısı tasarımı, bağlayıcı kalıntıları, çekme/anizotropi gibi diğer faktörlerin yüzey üzerindeki dolaylı etkileri değerlendirilmektedir. Bu kapsamda derlenen bilgiler, MEX yöntemiyle üretilen metal parçaların yüzey kalitesini artırmaya yönelik iyileştirme çalışmalarına yön vermeyi amaçlamaktadır.

2. MEX/M YÖNTEMİ VE SÜRECİ

MEX/M yönteminde üretim süreci temel olarak üç aşamadan oluşur. Bu aşamalar sırası ile baskı (şekillendirme), debinding (bağlayıcı giderme) ve sinterleme olarak tanımlanabilir. İlk aşamada yüksek oranda metal tozu içeren termoplastik bir filament, bir FDM tipi yazıcıda

eritilerek katmanlar halinde üst üste serilir ve istenen geometriye sahip "yeşil parça" oluşturulur. Kullanılan filamentler tipik olarak hacimce %50–60 oranında metal tozu ve polimer bağlayıcı karışımından oluşur. Yeşil parça alındıktan sonra ikinci aşama olan bağlayıcı uzaklaştırma (debinding) işlemine geçilir. Bu adımda, parçaya şeklini veren polimer bağlayıcıların büyük kısmı uygun yöntemlerle uzaklaştırılır. Bağlayıcı uzaklaştırma genellikle iki kademede gerçekleştirilir. Önce yeşil parça bir çözücü ortama daldırılarak bağlayıcının çoğunluğu çözülür ardından kontrollü bir ısıl işlemle geriye kalan bağlayıcılar düşük ısı artış hızıyla yakılarak uçurulur. Debinding sonucunda geriye metal tozu iskeletinden oluşan "kahverengi parça" kalır (Li vd., 2006). Bu parça halen gözenekli ve mekanik olarak zayıf bir yapıya sahiptir ancak son şekil korunmuştur. Sinterleme işleminde, kahverengi parça koruyucu bir atmosfer altında yüksek sıcaklığa (metal tozunun erime noktasının altına) ısıtılır. Bu sayede metal partiküller difüzyonla birbirine kaynayarak yoğun, tek parça bir yapı oluşturur. Sinterleme sırasında parça hacminde belirgin bir küçülme meydana gelir. Bu küçülmenin sebebi uzaklaştırılan bağlayıcıdan boşalan gözenekler kapanması ve metal tozlarının daha sıkı bir form almasıdır. Nihai sinterlenmiş parça, neredeyse tamamen metal özellikleri gösteren, belirli oranda (genelde %95+ yoğunlukta) bir malzemedir. Bağlayıcı uzaklaştırma ve sinterleme adımları, elde edilen parçanın boyutsal doğruluğunu ve mekanik özelliklerini büyük ölçüde belirler; bu nedenle bu süreç parametrelerinin optimizasyonu kritik öneme sahiptir.



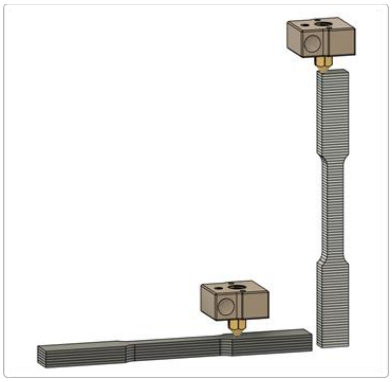
Şekil 1. MEX/M parça üretim sürecinin şematik gösterimi (Liu, vd. 2020).

MEX/M sürecinde yaygın olarak kullanılan metal malzemeler arasında paslanmaz çelikler (özellikle 17-4 PH ve 316L), takım çelikleri (H13 vb.), titanium (Zhang vd. 2020) ve alüminyum alaşımları ile bakır, pirinç, nikel bazlı alaşımlar sayılabilir . Başlangıçta 17-4 PH ve 316L paslanmaz çelik filamentler ticari olarak yaygınken son yıllarda titanyum ve alüminyum gibi yeni malzemeler için de MEX/M araştırmaları yapılmaya başlanmıştır (Sadaf vd., 2024, Lengauer vd., 2018, Ramazani vd., 2022). Filament formundaki bu yüksek dolgu içerikli malzemelerin baskı parametreleri, başarılı bir baskı almak için dikkatlice ayarlanmalıdır. Baskı parametrelerinin her biri ürün kalitesine etki etse de, literatürde baskı oryantasyonu ve sinterleme koşullarının, özellikle yüzey pürüzlülüğü açısından en belirleyici faktörler olduğu vurgulanmıştır (Boschetto, vd., 2022).

2.1. Baskı Yönü ve Yüzey Kalitesi

Eklemeli imalat süreçlerinde baskı yönü, parçanın yazıcı tablasına göre konumunu ve dolayısıyla katmanların yerleşim açısını ifade eder. Bu yönelim, MEX/M ile üretilen metal

parçaların hem mekanik özelliklerinde hem de yüzey kalitesinde belirleyici rol oynar. Parça, farklı yönlerde basıldığında katmanların birbirine göre dizilişi ve destek gereksinimleri değişeceğinden, ortaya çıkan yüzey pürüzlülüğü de önemli ölçüde değişiklik gösterebilir. Özellikle karmaşık veya eğimli yüzey geometrilerine sahip parçalar için doğru baskı yöneliminin seçimi kritik hale gelmektedir.



Şekil 2. MEX/M yönteminde baskı yöneliminin yüzey oluşumuna etkisinin şematik gösterimi: (a) Yatay baskı (parça XY düzleminde), (b) Dikey baskı (parça Z ekseninde) (Ceylan, 2025).

Yatay yönde basılan bir parçada katmanlar nesnenin uzunlamasına ekseni boyunca sıralanır. Bu durumda özellikle düşey yüzeylerde belirgin katman izleri gözlemlenir. Buna karşılık dikey baskıda katmanlar parçanın yüksekliği boyunca üst üste dizilir ve yatay düzlemdeki yüzeyler katmanlar halinde oluşur. Sonuç olarak, baskı oryantasyonu parçanın belirli yüzeylerinin pürüzlülüğünü artırıp azaltabilir; örneğin yatay baskıda üst üste yığılan katmanlar, yan yüzeylerde merdiven basamağı etkisine yol açarken, dikey baskıda parçanın yan yüzeyleri daha düzgün, ancak üst yüzeyleri katmanlı bir yapı sergileyebilir. Uygun yönelim seçilerek kritik yüzeylerdeki katman geçişlerinin en aza indirilmesi mümkündür.

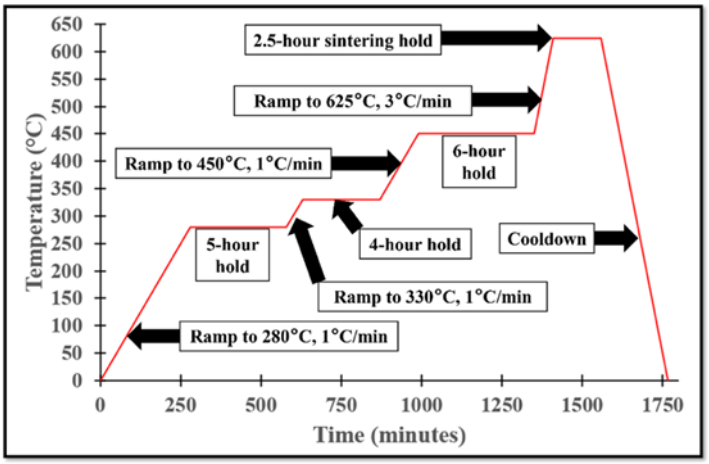
Baskı yöneliminin yüzey pürüzlülüğü üzerindeki etkisinin sayısal boyutu, parça geometrisine ve katman kalınlığı gibi diğer parametrelere bağlıdır. 316L paslanmaz çelik üzerinde yapılan bir çalışmada, yatay ve dikey baskı yönlerinde ölçülen ortalama yüzey pürüzlülüğü değerlerinin farklı olduğu, genel olarak yatay baskıda pürüzlülüğün daha yüksek çıktığı belirtilmiştir (Boschetto vd., 2022). Başka bir çalışmada ise farklı yatay açıyla (0°, 45°, 90°) basılan yüzeylerin pürüzlülüklerinde anlamlı farklar bulunmuştur (Sukindar vd., 2024). Bu farklılıkların temelinde yatan mekanizma, eklemeli imalatın doğasındaki katmanlı yapı ve katmanlar arası bağlanma kalitesidir. Baskı yönelimi sadece pürüzlülüğü değil, aynı zamanda parçanın mekanik özelliklerini ve boyutsal doğruluğunu da etkiler. Katmanlar arası bağların yönü, uygulanan yüke göre değiştiği için, örneğin dikey baskıda (katmanlar dikey eksende üst üste) üretilen bir parçanın xy-düzlemindeki (yan) mukavemeti, aynı parçanın yatay baskıda üretilmesine göre farklı olabilir. Ancak yüzey kalitesi açısından bakıldığında, pürüzsüz bir yüzey istenen uygulamalarda baskı yönelimi seçimi kritik bir yüzeyin olabildiğince düz çıkmasını sağlayacak şekilde planlanmalıdır. Örneğin, estetik açıdan önemli görünen bir yüzeyin yüzey pürüzlülüğünü en aza indirmek için o yüzeyin yazıcı tablasına dik (dikey) konumda basılması tercih edilebilir. Aksine, eğer belirli bir yüzeyde katman izleri tolere edilebilirse veya sonradan işleme tabi tutulacaksa, parça farklı bir yönde basılabilir.

Sonuç olarak, baskı yönü MEX/M sürecinde üretilecek parçanın yüzey karakteristiğini doğrudan belirleyen bir faktördür. Tasarımcı veya operatör, parça kullanım amacına göre en uygun yönü belirlemelidir. Mekanik dayanımın kritik olduğu durumlarda yük yönüyle katmanların hizalanması gerekirken, yüzey kalitesinin ön planda olduğu uygulamalarda

katman izlerinin en az görüleceği oryantasyonlar tercih edilmelidir. Böylelikle, istenen yüzey pürüzlülüğü değeri mümkün olan en az ek işlemle elde edilebilir. Baskı yönü seçimi, çoğu zaman birtakım özellikler için başka özelliklerden feragat etmeyi gerektirir. Çünkü en iyi yüzey kalitesi ile en iyi mekanik performans aynı yönde sağlanamayabilir.

2.2. Sinterleme Parametreleri ve Yüzey Kalitesi

MEX/M yöntemiyle üretilen yeşil parçanın nihai metal hale gelmesi, uygulanan sinterleme işlemi sayesinde gerçekleşir. Sinterleme sıcaklığı, sinterleme süresi ve fırın atmosferi gibi parametreler, parçanın mikroyapısal gelişimini ve dolayısıyla yüzey özelliklerini büyük ölçüde etkiler. Literatürde, bu parametrelerdeki değişimlerin parça yoğunluğu, sertliği ve boyutsal kararlılığı üzerindeki etkileri kapsamlı biçimde incelenmiştir; burada özellikle yüzey kalitesiyle ilişkili bulgular üzerinde durulmaktadır. Daha yüksek sinterleme sıcaklığı ve/veya daha uzun sinterleme süresi, parçanın bağ dayanımını ve yoğunluğunu arttırmaktadır (Yoon vd., 2003). Sinterleme süreci malzeme çeşidine göre farklılık arz edebilir. Şekil 3'te metal parça üretiminde kullanılan tipik bir debinding ve sinterleme sıcaklık grafiği gösterilmektedir. Al6062 malzeme için tanımlanan süreç 280 °C, 330 °C ve 450 °C'de sırasıyla 5, 4 ve 6 saatlik bekletmelerin ardından 625 °C'ye 3 °C/dk hızla çıkılarak 2,5 saatlik sinterleme ile tamamlanmaktadır. Yeterince yüksek bir sıcaklıkta, metal tozları arasında difüzyon ve boyun oluşumu maksimum düzeyde gerçekleşir. Parça içindeki gözeneklilik azalır ve malzeme taneleri büyüyerek sağlam bir yapı ortaya çıkar. Bunun sonucunda yüzeydeki mikro boşluklar ve pürüzlülüğe katkı veren gözenekli yapı kısmen yok olarak daha düzgün bir yüzey elde edilebilir. Nitekim sinterleme sıcaklığının ısıtılabilir maksimum değere yaklaştırılmasının ve birkaç saatlik bir fırınlama süresinin, 316L paslanmaz çelik MEX parçalarının yoğunluğunu %95'ten %98'e çıkardığı ve açık gözenekliliği büyük ölçüde azalttığı bildirilmiştir (Sadaf vd., 2021; Yoon vd., 2003). Bu gelişim yüzey pürüzlülüğü değerlerine de yansımakta, düşük sıcaklıkta veya kısa süre sinterlenmiş numunelere kıyasla yüksek sıcaklıkta uzun süre sinterlenen numunelerin daha düşük Ra değerlerine sahip olduğu gözlemlenmektedir. Ancak, aşırı yüksek sıcaklık veya gereğinden fazla uzun sinterleme süresi her zaman pozitif etki yaratmaz. Tane büyümesi, çarpılma ve sarkma gibi istenmeyen durumlar da ortaya çıkabilir. Özellikle karmaşık şekilli parçalar, çok yüksek sıcaklıklarda kendi ağırlıkları altında eğilebilir veya hassas boyutsal özelliklerini kaybedebilir. Bu yüzden, sinterleme programı belirlenirken hedeflenen yoğunluk ve mekanik özellik ile boyutsal doğruluk arasında bir denge kurulmalıdır.



Şekil 3. MEX/M yöntemi ile üretilmiş Al6061 malzemenin sinterleme grafiği (Malone vd. 2022)

Sinterleme sürecinin gerçekleştirildiği atmosfer (fırın gaz ortamı) da metal parça yüzey kalitesi üzerinde önemli bir etkiye sahiptir. Çoğu metal için sinterleme işlemi inert gaz (argon, azot vb.) veya vakum atmosferinde yapılır. Ancak paslanmaz çelik gibi kendiliğinden pasivasyon tabakası oluşturan malzemelerde reduktif (indirgeme) atmosfer kullanmak büyük avantaj sağlar. Özellikle hidrojen içeren atmosferler, yüksek sıcaklıkta metal yüzeylerindeki oksitleri azaltarak temiz metal yüzey oluşmasını teşvik eder. Örneğin (Silvain vd., 2023) tarafından yapılan bir çalışmada, 316L paslanmaz çelik parçaların hava ortamında sinterlenmesi durumunda yüzeylerinde ve tane sınırlarında krom oksit zenginleşmeleri görülürken, aynı parçaların %100 hidrojen veya %95 Ar + %5 H2 atmosferinde sinterlenmesi sonucu yüzey oksitlerinin büyük oranda giderildiği tespit edilmiştir. Bu da sinterlenmiş parçanın yüzey renginin daha parlak/metalik olmasını ve pürüzlülüğün mikroyapısal düzensizliklerden arınmasını sağlamaktadır. Ayrıca hidrojen, sinterleme sırasında bağlayıcı bozunmasından arta kalan karbon kalıntılarını da uzaklaştırarak (uçucu hidrokarbonlara dönüştürerek) gözeneklerde birikmesini engeller. Böylece yüzey bütünlüğünü ve saflığını iyileştirdiği görülmüştür (Silvain vd., 2023). Sinterleme parametrelerinin yüzey kalitesine etkisini değerlendiren araştırmalar, çoğunlukla yüzey pürüzlülüğü ölçümleri ve mikroyapısal analizler üzerinden sonuçlar sunmaktadır. Örneğin Boschetto vd. çalışmalarında 316L numuneleri farklı sıcaklık ve süre kombinasyonlarında sinterleyerek hem yoğunluk hem de yüzey pürüzlülüğü ölçümleri yapmış; yüksek sıcaklıkla birlikte Ra değerinde belirgin düşüşler kaydetmişlerdir (Boschetto vd., 2023). Benzer şekilde hidrojen atmosferinin kullanıldığı sinterleme işlemlerinde parça yüzeyinin daha temiz ve parlak olduğu SEM/EDS analizleriyle doğrulanmış, oksit tepeciklerinin ve yüzey pullanmalarının kaybolduğu görülmüştür (Silvain vd. 2023). Ancak atmosferin uygun olmadığı durumlarda parça yüzeyinde ince bir oksit tabakası kalabildiği ve bunun hem görünümü matlaştırıp pürüzlülüğünü artırabildiği hem de korozyon direncini olumsuz etkilediği belirtilmektedir. MEX/M sürecinde uygulanan sinterleme işleminin koşulları, elde edilen metal parçanın nihai yüzey kalitesini önemli ölçüde belirler. İstenilen özelliklere ulaşmak için sinterleme sıcaklığı ve süresi optimize edilmeli; malzemeye uygun atmosfer seçilmelidir. Örneğin 316L paslanmaz çelik için literatürde genellikle ~1360°C civarında 2–4 saatlik bir sinterleme, %100 H2 veya vakum atmosferde önerilmektedir (Sadaf vd., 2021, Silvain vd., 2023). Bu koşullar altında yüksek yoğunluklu ve temiz yüzeyli parçalar elde etmek mümkün olmaktadır. Sinterleme parametrelerinin uygun kombinasyonu, sadece yüzey pürüzlülüğünü değil, aynı zamanda parçanın boyutsal hassasiyetini ve iç yapısını da iyileştirecektir. Aşağıdaki tartışma bölümünde, sinterleme parametreleri ile baskı yönelimi arasındaki etkileşim ve diğer yan faktörlerin yüzey kalitesine toplu etkisi değerlendirilmektedir.

3. SONUÇLAR ve TARTIŞMA

MEX/M yöntemi, içerdiği yüksek bağlayıcı oranı nedeniyle parçalarda anizotropik çekme davranışları ortaya çıkarabilmektedir. Baskı yönünde (XY düzleminde) ve katman yönünde (Z ekseninde) farklı oranlarda büzülme gözlenmesi olasıdır. Örneğin Liu ve arkadaşlarının çalışmasında, 17-4 PH paslanmaz çelikten basılan test çubuklarının sinterleme sonrası uzunluklarında %20,3, kalınlıklarında ise %15,2 oranında küçülme ölçülmüştür (Liu vd., 2020). Bu sonuç, Z yönünde daha fazla boşluk kaldığı ve bu doğrultuda daha fazla sinterleme büzülmesi meydana geldiği şeklinde yorumlanmaktadır. Baskı yönelimi yalnız mekanik özellikleri değil, sinterleme sonrası boyutsal doğruluğu ve dolaylı olarak yüzey kalitesini de tayin etmektedir. Özellikle büyük düzlemsel yüzeyler veya ince duvarlı yapılar, anizotropik çekme nedeniyle eğilme/çarpılma gösterebilir ve yüzey düzgünlüğü bozulabilir. Bu nedenle, karmaşık parçaların basımında yönelime karar verirken hem yüzey pürüzlülüğü

hem de sinterleme sonrası şekil değişimleri birlikte göz önüne alınmalıdır. Baskı yöneliminin yüzey kalitesine etkisi çoğu çalışmada benzer eğilimler gösterse de, bazı durumlarda uygulanan baskı stratejileri bu etkiyi azaltabilir. Örneğin, FFF baskı tekniğinde kullanılan "ütüleme (ironing)" gibi bir ince katman geçme tekniği, yatay üst yüzeylerin pürüzlülüğünü azaltmak için uygulanmaktadır (Tosto vd. 2021). Metal MEX'de de benzer şekilde yeşil parçaya baskı esnasında ekstra bir yüzey düzleştirme katmanı eklenmesi veya son katmanı daha ince basma gibi yaklaşımlar araştırılmış ve yüzey pürüzlülüğünde iyileşme sağlanmıştır. Bununla birlikte, bu tür teknikler her geometride ve metal filament için kolay uygulanamayabilir. Çünküa metal filamentlerin akış özellikleri plastikler kadar esnek değildir. Dolayısıyla yüzey kalitesini arttırmanın anahtarının hala uygun baskı yönelimi seçimi ve gerekirse baskı sonrası ek işlemler olduğu söylenebilir (Grzelak vd., 2020). Sinterleme parametreleri açısından bakıldığında, sıcaklık ve süre optimizasyonunun sadece yüzey pürüzlülüğüne değil, parçanın mikro-yapısal homojenliğine de etki ettiği görülür. Yeterli sinterleme olmaması durumunda yüzeyde belirgin gözenekler veya bağlayıcı kalıntılarının bıraktığı boşluklar kalabilir. Bu da yüzey pürüzlülüğünü artırdığı gibi parça mukavemetini de düşürür. Özellikle bazı çeliklerde aşırı yüksek sıcaklıklarda, büyük tane sınırları yüzey topografyasını etkileyebilmektedir. Bu nedenle literatürde birçok çalışma, optimum sinterleme koşullarının belirlenmesini odağına almıştır. Örneğin, çeşitli araştırmalarda 316L çelik için ~1350°C civarı ısıtmada 3-4 saat sinterlemenin en iyi yoğunluk-yüzey kalitesi dengesi sağladığı belirtilmiştir (Suwanpreecha vd., 2022, Yoon vd., 2003; Nurhudan vd., 2021). Yüzey kalitesini etkileyen diğer bir husus da bağlayıcı uzaklaştırma adımının etkinliğidir. Eğer bağlayıcı uzaklaştırma tam olarak gerçekleşmez ve parça içinde/büyük gözeneklerde bağlayıcı kalıntıları kalırsa, sinterleme sırasında bu kalıntılar gaz oluşturarak mikro boşluklara veya yüzeyde istenmeyen kalıntılara sebep olabilir. Bu da sinterlenmiş parçanın yüzeyinde pürüzlülük artışına ve hatta mikroyapısal kusurlara yol açar. İyi bir bağlayıcı uzaklaştırma, yüzey kalitesi için ön koşuldur denilebilir. Çözücüyle bağlayıcı uzaklaştırma ve ardından termal bağlayıcı uzaklaştırma süreçlerinin uygun kombinasyonu, yüzey bütünlüğünü korumak adına önemlidir. Ayrıca, MEX/M ile üretimde destek yapılarının tasarımı da yüzey kalitesine etki eder. Destek kullanılan yüzeylerde, destek bağlantı noktalarının izleri kalabilir ve sinterleme sonrası bu bölgelerde yüzey pürüzlülüğü artmasına sebep olabilir. Bu nedenle kritik yüzeylerin mümkünse destek gerektirmeyecek şekilde konumlandırılması ya da destek temas alanlarının en aza indirilmesi önerilir. Desteklerin kaldırılması sonrasında yüzeyde kalan izler, gerekirse hafif zımpara veya kumlama gibi yöntemlerle giderilerek yüzey kalitesi iyileştirilebilir (Grzelak vd., 2020). Destek stratejisi, baskı yönelimiyle birlikte düşünülmesi gereken bir konudur; doğru planlanmadığında desteklerin parça yüzeyinde bıraktığı pürüzler toplam yüzey kalitesini düşürebilir.

Baskı yönelimi ve sinterleme koşulları MEX/M yönteminde iç içe geçen ve birlikte parçanın yüzey oluşumunu belirleyen parametrelerdir. Kötü bir baskı yönelimi seçimi, ne kadar ideal sinterleme yapılırsa yapılsın yüzeyde istenmeyen izler bırakacaktır. Benzer şekilde, yetersiz sinterleme koşulları, en uygun baskı oryantasyonunda basılmış olsa bile parçanın yüzeyinin gözenekli ve pürüzlü kalmasına neden olacaktır. Bu nedenle, yüksek kaliteli bir yüzey elde etmek, baskı ve sinterleme parametrelerinin bütünsel optimizasyonunu gerektirir. Literatürde son dönemde yayımlanan çalışmalar, bu parametrelerin optimizasyonunu yapay zekâ teknikleri kullanarak ele almakta ve çok değişkenli optimizasyonlar gerçekleştirmektedir (Cerlincă vd., 2024). Böylece hem boyutsal hem mekanik hem de yüzey kriterleri aynı anda sağlanmaya çalışılmaktadır.

4. DEĞERLENDİRME

Metal Malzeme Ekstrüzyonu (MEX/M), metal parça üretiminde düşük maliyetli ve erişilebilir bir alternatif olarak öne çıkmaktadır. Bu yöntemin, yüksek ekipman giderlerine sahip toz yataklo sistemlere kıyasla daha basit ve güvenli oluşu, kullanım alanlarını her geçen gün genişletmektedir. Bununla birlikte, MEX/M ile üretilen parçaların yüzey kalitesi, sürecin doğası gereği bazı sınırlamalara sahiptir. Bu bildiride literatürdeki çalışmalar ışığında, baskı yönelimi ve sinterleme koşullarının söz konusu yüzey kalitesi üzerindeki etkileri incelenmiştir. Elde edilen bulgular baskı oryantasyonunun parçanın yüzey pürüzlülüğünü doğrudan etkilediğimi göstermektedir. Parçaların dikey yönde basılması, katman izlerini azaltarak daha düzgün yüzeyler sağlayabilmekte; yatay baskı ise özellikle yan yüzeylerde belirgin adımlanma efektine yol açarak pürüzlülüğü artırmaktadır. Dolayısıyla, istenen yüzey kalitesine ulaşmak için parça baskı yönünün dikkatli planlanması gerekmektedir. Sinterleme koşulları da yüzey bütünlüğünde kritik rol oynamaktadır. Yüksek sıcaklık ve yeterli süreli sinterleme, malzeme yoğunluğunu artırıp yüzeydeki gözenekleri minimize ederek pürüzlülüğü düşürmekte; uygun bir atmosfer (örn. hidrojen) kullanımı ise yüzeyde oksit oluşumunu engelleyerek daha parlak ve temiz bir görünüm elde edilmesini sağlamaktadır. Ancak, çok yüksek sıcaklık veya uzun süreler boyutsal kararlılığı olumsuz etkileyebileceğinden, sinterleme parametrelerinin optimize edilmesi şarttır (Seensattayawong vd., 2023).

Baskı yönü ve sinterleme kombinasyonu yanında, sinterleme sonrası deformasyonlar, anizotropik çekme ve bağlayıcı kalıntıları gibi faktörler de yüzey kalitesine etki etmektedir (Silvain vd., 2023). Parça tasarım aşamasında bu etkiler öngörülmeli ve gerekiyorsa telafi edici önlemler (örneğin, ölçek faktörü uygulama, uygun destek yerleşimi) alınmalıdır. MEX/M yöntemiyle üretilen metal parçalarda yüzey kalitesini iyileştirmek ve yöntemin potansiyelini tam olarak kullanabilmek için daha fazla araştırmaya ihtiyaç duyulmaktadır. Özellikle yeni filament malzemelerinin geliştirilmesi, ısıl işlem optimizasyonları ve baskı sonrası yüzey işleme tekniklerinin entegrasyonu, bu alandaki gelecek çalışmalar için önemli görülmektedir. Sonuç olarak, MEX/M yöntemi doğru parametre kombinasyonlarıyla uygulandığında, metal ve hatta seramik-kompozit parça üretiminde geleneksel yöntemlere bir alternatif veya tamamlayıcı olma potansiyelini taşımakta, uygun koşullar sağlandığında yeterli yüzey kalitesi ve performansta parçalar elde edilebilmektedir.

Öte yandan, MEX/M yöntemi bazı kısıtları da beraberinde getirmektedir. Polimer-bağlayıcı içerikli filamentler kullanılmasının bir sonucu olarak, MEX/M baskılarında bağlayıcı oranı metal enjeksiyon kalıplamaya kıyasla daha yüksektir. Bu da "yeşil parça" dan sinterlenmiş parçaya geçerken daha büyük oransal çekmelere yol açar (Suwanpreecha ve Manonukul, 2022). Nitekim, literatürde MEX/M yöntemiyle üretilen sinterlenmiş metal parçalarda tipik doğrusal çekme oranlarının %15–20 aralığında olduğu bildirilmektedir (Kendziora vd. 2022, Ceylan vd. 2024). Bu değer, genellikle MIM parçalarındaki çekmeden daha yüksektir ve tasarım aşamasında bu farkın dikkate alınmasını gerektirir (Suwanpreecha ve Manonukul, 2022). Ayrıca, MEX/M sürecinin katmanlı yapısı nedeniyle, elde edilen metal parçaların yüzey pürüzlülüğü genellikle diğer metal baskı tekniklerine oranla daha yüksektir. Ancak Kluczyński vd. yaptıkları çalışmada 316L paslanmaz çelik parçalarda 0XY düzleminde MEX ve SLM yöntemleriyle ortalama yüzey pürüzlülüğü (Ra) yaklaşık değerler elde ederken (~5–6 µm), 0XYZ düzleminde MEX/M'de elde edilen yüzey pürüzlülüğü (~3.90 µm) SLM'in (~7.02) yarısı kadar ortaya çıkmıştır (Kluczyński vd. 2023). Ancak Rz değerine göre SLM'in daha düşük yüzey pürüzlülüğü değerlerine sahip olduğu görülmüştür.

Metallerin Malzeme Ekstrüzyonu (MEX/M) teknolojisinin geleceği, yüzey kalitesi ve mekanik özelliklerdeki sınırlamaların aşılmasıyla şekillenmektedir. Katmanlar arasındaki mikro boşluklar, sinterleme sırasında oluşan büzülmeler ve yüzeyde birikmiş oksitler, MEX/M

parçalarının yüzey kalitesini olumsuz etkileyebilmektedir. Bu nedenlerle, MEX/M teknolojisinin metal parça üretiminde yaygın biçimde kullanılabilmesi için yüzey kalitesinin iyileştirilmesi kritik bir araştırma konusu haline gelmiştir. Yapay zeka destekli süreç optimizasyonu, yüzey pürüzlülüğü ve yoğunluk gibi kritik kalite parametrelerinin tahmini için makine öğrenme modellerinin kullanılmasını teşvik etmektedir. Yeni filament malzemeleri, sinterleme sonrası daha yüksek yoğunluk ve mekanik dayanım sağlayarak nihai parça kalitesini artırmaktadır. Hibrit ve çok malzemeli baskı sistemleri, fonksiyonel dereceli yapılar ve entegre özelliklere sahip parçaların üretimini mümkün kılmaktadır. Gelişmiş yüzey işleme teknikleri, sinterleme sonrası yüzey kalitesini iyileştirmektedir. Standartlaşma ve kalite kontrol protokolleri, MEX/M ile üretilen parçaların endüstriyel uygulamalarını artırmak için önem kazanmaktadır. Bu gelişmeler, MEX/M teknolojisinin daha geniş bir uygulama yelpazesinde etkin bir şekilde kullanılmasını sağlayarak, geleneksel üretim yöntemlerine güçlü bir alternatif oluşturacaktır.

TEŞEKKÜR

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POLYSTYRENE/TiO_2 NANOCOMPOSITES: A STUDY ON DIELECTRIC PROPERTIES

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ABSTRACT
Polystyrene (PS) is an ideal main matrix for improving the optical and dielectric characteristics of nanocomposites due to its durability, transparency, high refractive index and good electrical insulation properties, and it is a functional polymer with a wide range of applications. PS-based nanocomposites are important materials in many areas such as photonics-based systems, sensors, dielectric capacitors and optoelectronic applications, and the development of their functional properties by combining them with nanomaterials offers a great research potential in the design of advanced technology materials. In this study, PS/TiO_2 nanocomposites were produced by adding different amounts of TiO_2 nanoparticles (1%, 4%, 8%, 16%) to the PS polymer base using the solvent evaporation method. The structural and electrical properties of these composites were investigated. X-ray diffraction (XRD) and Fourier Transform Infrared (FTIR) spectroscopy were used to determine the structural properties, and dielectric spectroscopy was used to determine the electrical properties. The results show that the incorporation of TiO_2 nanoparticles causes structural changes especially in the PS base polymer and is observed by the change in crystal size, crystallization rate and chemical bond structure. The effect of TiO_2 addition on the dielectric permittivity properties and ac electrical conductivity of these nanocomposites was investigated at ambient temperature. In addition, when the effect of TiO_2 nanoparticles on the dielectric properties and AC conductivity properties of the PS base polymer was examined, it was determined that the increasing nanoparticle addition rate improved the properties of the nanocomposites. The dielectric constant, dielectric loss and loss tangent decreased with increasing frequency and the dielectric constant values (1kHz) were found to be almost high (~21). It was concluded that these nanocomposites can be used in industrial and sensor-based applications such as capacitors and memory devices and the addition of nanoparticles will significantly improve the material performance of PS nanocomposites.
Keywords: Dielectric material, nanocomposite, polystyrene, TiO_2.

INTRODUCTION

Polymeric materials are preferred in dielectric applications due to their flexibility, ease of fabrication, high electrical breakdown strength, low dielectric losses and economic advantages. However, since most polymers have a low relative dielectric constant ($\varepsilon' < 10$), the use of these materials in a wide range of industrial applications is limited. To overcome this limitation, nanoparticles with high dielectric constants are added to polymer matrices to form composite materials, thereby increasing the overall dielectric performance of the material. The homogeneous distribution of nanoparticles in the polymer matrix creates large interfacial areas, improving electrical and dielectric properties. Such modifications make it possible to use polymers in a wider range of applications in fields such as electronics and electrical engineering. (Chen et al., 2025; Salim et al., 2025)(Alghunaim, 2019 ;Gaabour, 2020).

Polystyrene (PS) is a widely preferred thermoplastic polymer due to its transparency, resistance to diluted acids and bases, low cost and easy processability. The properties of PS can be modified by various methods such as physical blending with different materials or copolymerization. Physical modification is done by blending with different polymers and this method is widely used today. The styrene moiety in PS has many properties such as flame resistance, rigidity and solvent resistance. PS has an amorphous structure and is susceptible to chemical attack by aromatic and chlorinated hydrocarbons, which leads to limitations in some application areas. Its optical properties make polystyrene ideal for optoelectronic applications, while the incorporation of nanometal oxide particles can significantly enhance its optical, structural and electronic properties. In conclusion, the versatile properties and modification capability of polystyrene make it an indispensable material in various industrial applications (AL-Rubaiawi et al., 2025; Gaabour, 2021; Sharma & Garg, 2023).

Titanium dioxide (TiO_2) is a widely used nanomaterial in polymer-based nanocomposites due to its excellent photocatalytic activity, chemical and thermal stability, non-toxicity, and cost-effectiveness. Compared to other nanomaterials like ZnO or Al_2O_3, TiO_2 offers unique advantages such as phase-dependent optical properties and compatibility with polymers, without adversely affecting their physical characteristics. These properties make TiO_2 an ideal candidate for enhancing the functionality of polymer composites. TiO_2-containing composites find applications in solar cells, UV filters, and gas sensors, owing to their ability to improve optical, structural, and electronic properties. Incorporating TiO_2 nanoparticles into polymer matrices enables the development of multifunctional materials with high performance, expanding their applicability across various industries (Rahimli et al., 2024; Ramazanov et al., 2018).

The primary objective of this study is to investigate the impact of incorporating titanium dioxide (TiO_2) nanoparticles at varying concentrations into a polystyrene (PS) matrix on its dielectric and electrical properties. Structural and chemical modifications induced by TiO_2 nanoparticles were analyzed using X-ray diffraction (XRD) and Fourier-transform infrared (FTIR) spectroscopy. These analyses revealed significant alterations in the PS matrix structure, correlating with changes in electrical conductivity and dielectric constant of the resulting nanocomposites. The findings demonstrate that increasing TiO_2 content leads to pronounced structural transformations within the PS matrix, substantially influencing the electrical performance of the nanocomposites. This study underscores the potential of PS/TiO_2 nanocomposites for applications in electronic and dielectric devices.

METHOD

Polystyrene (PS)/Titanium Dioxide (TiO_2) nanocomposites were synthesized using the solution evaporation method, incorporating TiO_2 into the PS matrix at varying weight percentages. To achieve a homogeneous solution, 1 gram of each PS/TiO_2 nanocomposite was dissolved in a toluene/n-hexane solvent mixture with a volume ratio of 7:5 (v/v) and stirred at

70 °C for 5 hours using a magnetic stirrer. The resulting solutions were then poured into glass Petri dishes for film formation. The prepared samples were designated as PST1, PST4, PST8, and PST16, corresponding to TiO_2 doping levels of 1%, 4%, 8%, and 16% by weight, respectively.

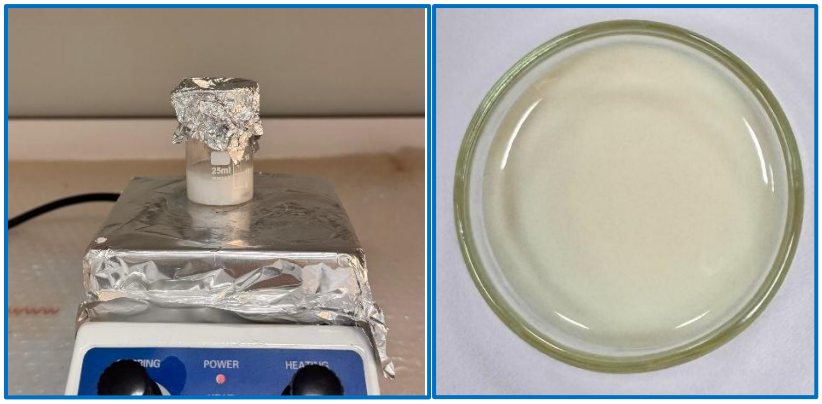

Figure 1. Image of the PS/TiO_2 nanocomposite solution and the resulting film prepared via the solution casting method.

Characterization

The XRD analysis was performed on a Rigaku Mini Flex II, employing Cu Kα radiation (λ = 1.5406 Å), scanning between 5° and 55° at 0.5° steps. To characterize the bonding structures of the samples, Fourier Transform Infrared (FTIR) spectroscopy was performed using a PerkinElmer Spectrum 100 FT-IR spectrometer. Spectra were recorded over the range of 4000 to 600 cm^{-1} with a resolution of 4 cm^{-1}, as illustrated in Figure 3. The dielectric properties of the PS/ZnO nanocomposites were analyzed using a Fytronix FY-7000 broadband dielectric spectrometer (Türkiye) over a frequency range of 1 kHz to 25 MHz, with an applied voltage of 1 V.

RESULTS

The structural properties of the PST1 nanocomposite were analyzed using X-ray diffraction (XRD) (Figure 2). In Figure 2, the broad peak at 2θ ≈ 20.42° indicates the characteristic amorphous structure of polystyrene. Notably, the peaks at 2θ = 24.84°, 26.38°, 38.56°, 46.14°, 48.68°, and 52.64° confirm the crystalline formation of TiO_2 in anatase and rutile phases. This suggests that TiO_2 nanoparticles are dispersed within the polystyrene polymer matrix. The absence of additional sharp peaks verifies that TiO_2 remains in an amorphous phase. (Rahimli et al., 2025).

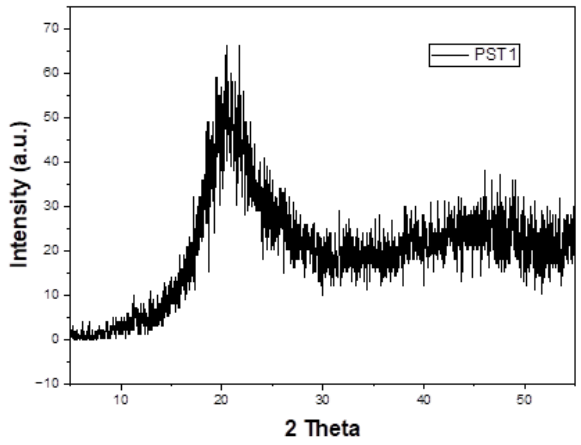

Figure 2. XRD spectra of PST1 nanocomposite.

Fourier Transform Infrared (FTIR) spectroscopy was utilized to investigate the chemical composition and molecular interactions within PS/TiO_2 nanocomposites. The FTIR spectra of the nanocomposite films, as depicted in Figure 3, were recorded over the spectral range of 4000 to 600 cm^{-1} for samples containing 1%, 4%, 8%, and 16% by weight of TiO_2. In the Figure 3, the C–H stretching vibrations associated with the benzene ring (3305–3026 cm^{-1}) and the asymmetric and symmetric C–H stretching vibrations in the polystyrene main chain (2926 and 2848 cm^{-1}) remained consistent across all samples. This consistency indicates that the incorporation of TiO_2 nanoparticles does not significantly alter the polystyrene's aromatic ring or main chain structure, suggesting that the C–H bonds are largely preserved despite varying TiO_2 concentrations.

FTIR analyses show a marked decrease in the characteristic peaks of pure polystyrene with increasing TiO_2 concentration in the range 1200-800 cm^{-1} in PS/TiO_2 nanocomposites. In particular, the peaks at wave numbers 1178, 1114, 1068 and 1025 cm^{-1} corresponding to the C-O stretching vibrations almost completely disappeared in samples containing 16% TiO_2. This suggests that the high TiO_2 content leads to strong interactions with the polystyrene matrix and these interactions cause weakening or breaking of C-O bonds under the temperature and pressure conditions applied during the preparation of nanocomposites. The intensity of the peaks at 749 and 620 cm^{-1} wave numbers decreases with increasing TiO_2 content. This suggests that the deformation and tensile vibrations of Ti-O bonds cause spectral shifts and decrease in peak intensities and that the interaction of TiO_2 with the polystyrene matrix leads to structural changes (Anju & Ramesan, 2024; Rahimli et al., 2024).

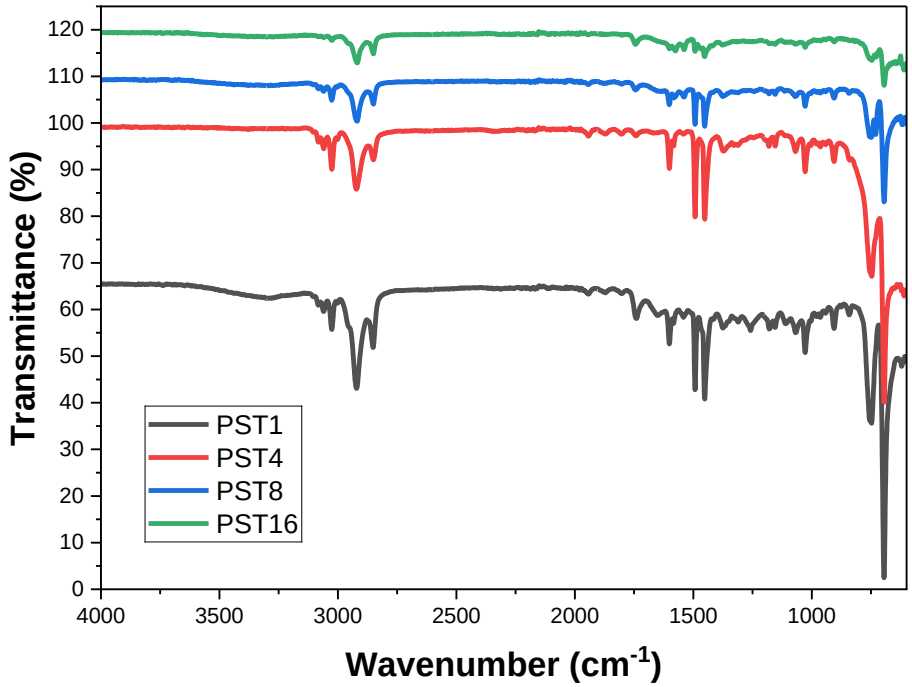

Figure 3. FTIR spectrum of PS/TiO_2 nanocomposites.

Dielectric properties

Figure 4(A) and 4(B) illustrate the variation of dielectric constant and dielectric loss, respectively, as functions of frequency for PS/TiO_2 nanocomposite samples with varying weight ratios, measured under ambient temperature. The dielectric constant (ε') of PS is generally reported to range between 2.4 and 3.0 under standard conditions. However, this value can vary significantly with frequency. For instance, measurements conducted within the 1 kHz

to 10 MHz frequency range have shown that the dielectric constant of PS can increase, reaching values between 6.5 and 8.6. This variation is attributed to frequency-dependent polarization mechanisms within the polymer matrix (Güner 2025)(Liu et al., 2023; Shalu et al., 2018).

The dielectric constant (ε') of PS exhibits a distinct frequency dependence. At lower frequencies, ε' tends to be higher due to polarization mechanisms such as dipolar and interfacial (Maxwell–Wagner–Sillars) polarization. These mechanisms involve the accumulation of charge carriers at interfaces within the polymer matrix, enhancing the material's ability to polarize in response to an electric field. As the frequency increases, the dielectric constant decreases. This decline is attributed to the reduced contribution of polarization, as dipoles and interfacial charges are unable to realign or accumulate rapidly enough to follow the swiftly alternating electric field. Consequently, the overall dielectric response diminishes at higher frequencies. For all samples, it was observed that the dielectric constant values were higher at low frequencies and decreased at high frequencies due to varying polarization phenomena within the polymer matrix (Figure 4A). These polarizations enhance the accumulation of charge carriers at the PS polymer matrix interface. As the dipoles in the composite grow, they become less effective at responding to alternating electric fields at higher frequencies, reducing polarization caused by charge accumulation (Cicek Ozkan & Guner, 2024;Rahimli et al., 2024).

The dielectric loss exhibits a frequency dependent behavior and this variation is closely related to the dynamics of the dipole and interfacial polarization mechanisms within the polymer matrix. At low frequencies, the dipole structures can easily align with the applied electric field, leading to increased energy loss and hence higher values of dielectric loss. However, as the frequency increases, it becomes more difficult for the dipoles to adapt to the rapidly changing electric field direction, leading to a decrease in dielectric loss. Furthermore, interfacial polarization (Maxwell-Wagner-Sillars effect) contributes significantly to the dielectric loss, especially at low frequencies. This phenomenon occurs as a result of charge accumulation at the interfaces between the polymer matrix and heterogeneous material components such as dispersed nanoparticles. As the frequency increases, the accumulation time of charges at these interfaces decreases, which reduces the effect of interfacial polarization on the dielectric loss. The dielectric constant of TiO_2-filled PS/TiO_2 nanocomposites varies from 12.62 to 20.56, while the dielectric loss varies from 0.87 to 1.42 at a frequency of 1 kHz. While TiO_2 at low ratios is homogeneously dispersed in the matrix, interactions and aggregation between particles may occur as the filler ratio increases. This makes the movement of charge carriers difficult, leading to an increase in the dielectric loss value (Figure 4B)(El Nahrawy et al., 2020; Mahani et al., 2024; Pervaiz et al., n.d.; Rahimli et al., 2024).

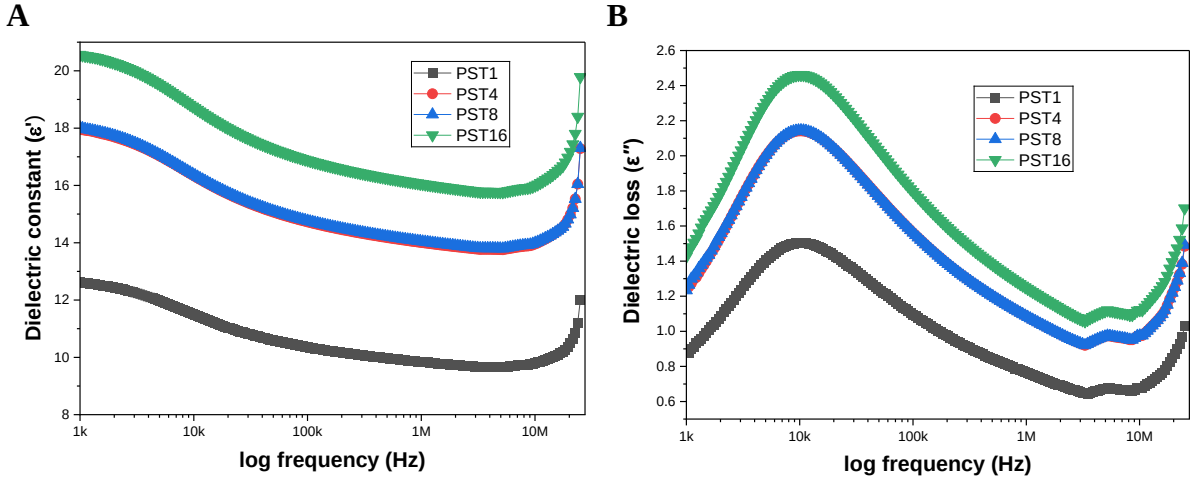

Figure 4. Dielectric constant (A) and dielectric loss (B) of PS/TiO_2 nanocomposites.

AC conductivity

The AC electrical conductivity of PS/TiO_2 nanocomposites was measured over a range of frequencies (1 kHz–25 MHz) and is presented in Figure 5. It was observed that the AC conductivity increases with increasing frequency. Among all PS/TiO_2 nanocomposites, PST16 exhibited the highest σ_{ac} value at 1 kHz, with a conductivity of 1.12×10^{-2} S/cm. The nonlinear increase in conductivity with frequency indicates the presence of non-ohmic type conduction. The lower conductivity observed at lower frequencies is attributed to the insulating grain boundaries, while the conductive grains are responsible for the conductivity behavior at higher frequencies. (Anju & Ramesan, 2024). AC conductivity measurements were performed to examine the conduction behavior of the nanocomposite films and the results are presented in Figure 5. In all samples, AC conductivity increases with frequency. This increase, especially at high TiO_2 content, is attributed to the ease of charge transport provided by better connectivity and percolative conduction resulting from the reduced distance between the filler particles. This is also supported by the well-dispersed structure of the nanoparticles in the polymer matrix. (Anju & Ramesan, 2024; Singh et al., 2015).

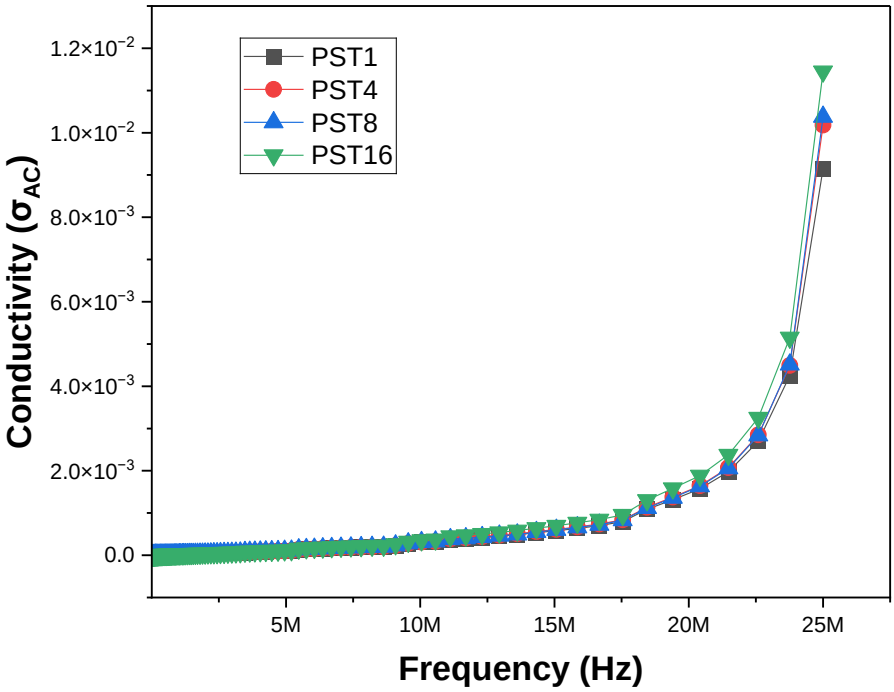

Figure 5. AC conductivity of PS/TiO_2 nanocomposites.

CONCLUSION

PS/TiO_2 nanocomposite films with varying TiO_2 content were successfully fabricated using the solution casting method, ensuring a homogeneous distribution. Structural characterization was performed using XRD and FTIR techniques, while dielectric properties were investigated in the frequency range of 1 kHz to 25 MHz under room temperature conditions. XRD results confirmed the formation of nanocomposites, and FTIR analysis supported the structural homogeneity with increasing TiO_2 content. The findings indicated that both AC conductivity and dielectric constant increased with rising frequency and filler concentration. Notably, the PS nanocomposite containing 16 wt% TiO_2 (PST16) exhibited the best electrical performance due to its highest dielectric constant and AC conductivity values.

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INCONEL 718 ALAŞIMININ İŞLENEBİLİRLİĞİ ÜZERİNE BİBLİYOMETRİK ANALİZ

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ÖZET
Bu çalışma, inconel 718 alaşımının işlenebilirliği konusundaki akademik yayınları bibliyometrik analiz yöntemiyle incelemektedir. Inconel 718, üstün mekanik ve termal özelliklere sahip, yüksek sıcaklık dayanımı ile öne çıkan bir nikel alaşımıdır. Ancak, işlenmesi oldukça zordur ve yüksek kesme kuvvetleri ile takım aşınmasına neden olur. Çalışmada, Web of Science (WoS) veri tabanında "inconel 718" ve "machining" anahtar kelimeleriyle yapılan taramalardan 2546 sonuç elde edilmiştir. Bu sonuçlar, yayınların yıllara, alanlara, anahtar sözcüklere, yazar ve ülkeler arasındaki iş birliğine göre analiz edilmiştir. Inconel 718'in işlenebilirliği ile ilgili yayınların 1981 yılında başladığını ve özellikle 2015'ten itibaren hızla arttığını ortaya koymaktadır. En sık incelenen işleme yöntemleri tornalama, frezeleme ve elektro erozyon işlemleridir. Anahtar sözcük analizinde “inconel 718”, “takım aşınması” ve “yüzey pürüzlülüğü” en sık kullanılan terimlerdir. Hindistan, Çin ve ABD, bu alandaki en üretken ülkeler olarak öne çıkmaktadır. Çalışma, konuyla ilgili araştırma yapmak isteyenler için önemli literatür kaynakları ve eğilimler sunarak rehber niteliği taşımaktadır. Bu tür bibliyometrik analizler, yeni araştırma alanlarının belirlenmesine ve işlenebilirlik sorunlarının çözümüne katkı sağlamayı amaçlamaktadır.
Anahtar sözcükler: inconel 718, takım aşınması, yüzey pürüzlülüğü, bibliyometrik analiz

BIBLIOMETRIC ANALYSIS ON THE MACHINABILITY OF INCONEL 718 ALLOY

ABSTRACT

This study examines academic publications on the machinability of the inconel 718 alloy using bibliometric analysis. Inconel 718 is a nickel-based alloy renowned for its superior mechanical and thermal properties, as well as its high-temperature resistance. However, it is challenging to machine and leads to high cutting forces and tool wear. The study analyzed 2,546 results obtained from searches conducted in the Web of Science (WoS) database using the keywords "inconel 718" and "machining." These results were evaluated based on publication years, fields, keywords, authors, and collaborations between countries. The findings reveal that publications on the machinability of inconel 718 began in 1981 and have significantly increased, especially since 2015. The most frequently studied machining methods are turning, milling, and electrical discharge machining. Keyword analysis identified “inconel 718,” “tool wear,” and “surface roughness” as the most commonly used terms. India, China, and the United States are the most productive countries in this field. This study provides key literature resources and trends, serving as a guide for researchers interested in this topic. Such bibliometric analyses aim to identify new research areas and contribute to solving machinability challenges.

Keywords: inconel 718, tool wear, surface roughness, bibliometric analysis

GİRİŞ

Süper alaşımlar, nikel, nikel-demir veya kobalt esaslı, yüksek sıcaklıklara dayanıklı ve üstün mekanik mukavemet özellikleri ile yüzey direnci sağlayan malzemelerdir. Bu alaşımlar, uçak gaz türbinleri, enerji santralleri, pistonlu motorlar, metal işleme, tıbbi cihazlar, uzay araçları, nükleer enerji, kimya ve petrokimya endüstrisi gibi birçok alanda kullanılmaktadır. Nikel bazlı süper alaşımlar genellikle %10-20 krom, %8'e kadar alüminyum ve titanyum, %5-15 kobalt ile az miktarda bor, zirkonyum, magnezyum ve karbon içerir. Ayrıca molibden, niyobyum ve tungsten gibi katkı maddeleri de kullanılır. Yüzey kararlılığını artırmak için özellikle krom ve alüminyum önemlidir [1].

Inconel 718, çökelme sertleşmesi ile güçlendirilmiş, 650 °C'ye kadar yüksek sıcaklıklarda mekanik özelliklerini büyük ölçüde koruyabilen bir nikel alaşımıdır. Bu alaşım, krom ve demir elementlerine ek olarak, niyobyum, molibden, titanyum ve alüminyum gibi elementler de barındırır [2]. Inconel 718, aynı zamanda işlenmesi en zor malzemelerden biri olarak da bilinir. İşleme sırasında karşılaşılan en büyük zorluklar, takım ömrünün kısalmasına ve üretim maliyetinin artmasına neden olan yüksek kesme kuvvetleri ve oluşan yüksek sıcaklıklardır [3]. Inconel 718'in işlenebilirliğini ve yüzey kalitesini artırmak, malzemenin mekanik ve termal performansını geliştirmek açısından büyük önem taşır. Alaşımın kimyasal bileşimi, mikro yapısı ve kullanılan işleme teknikleri bu süreçte belirleyici rol oynar. Belirli elementlerin (B, C, Re ve Ru gibi) alaşımdaki oranı, tane sınırı dayanımını ve yüksek sıcaklık davranışını iyileştirirken, Mg gibi bazı elementlerin aşırı miktarları mekanik özellikleri olumsuz etkileyebilir. Mikro yapıdaki farklı fazlar, alaşımın mukavemeti ve çatlama direncini şekillendirir. Ayrıca, minimum miktarda yağlama (MQL), ultrasonik destekli işleme (UAM) ve lazer destekli işleme (LAM) gibi ortamlarının seçimi ve kesme yöntemleri, sürtünmeyi ve aşınmayı azaltarak işlenebilirliği artırır. İşleme sırasında kesme kuvvetleri, enerji tüketimi, takım aşınması ve yüzey pürüzlülüğü gibi parametreler, kullanılan işleme koşullarıyla doğrudan bağlantılıdır. Bu unsurların optimize edilmesi, Inconel 718'in daha verimli işlenmesini ve dayanıklı parçalar üretilmesini mümkün kılar [4].

Inconel 718'in işlenebilirliğinin bilimsel olarak geliştirilmesi ve farklı sektörlerde uygulanması büyük kolaylıklar sunacaktır. Bilimsel gelişim ise, mevcut çalışmaların gözden geçirilmesi ve boşlukların tespit edilmesiyle sağlanmaktadır. Bibliyometrik analiz, mevcut çalışmaların gözden geçirilmesi ve değerlendirilmesi amacıyla uygulanabilir. Bibliyometrik analiz sayesinde, anahtar kelimeler, ülkeler, yazarlar, kurumlar ve dergilerin üretkenliği; gelişmiş veya gelişmesi gereken araştırma konuları; literatürdeki eksiklikler; iş birliği bağlantıları ve bir konudaki çalışmaların geniş kapsamlı etkileri üzerine sayısal verilere ulaşılabilir. Günümüzde, literatür taramasının hazırlık adımı olarak da kullanılabilen bibliyometrik analiz, birçok sınırlamaya sahip olmasına rağmen, herhangi bir araştırmanın ilk adımı olarak önem arz etmektedir [5].

Inconel 718 alaşımının işlenebilirliği ve birçok çeşitli alanda kullanımı ve gelişimi gün geçtikçe önem kazanmıştır. Bu konu ile ilgili olarak yapılan araştırmalara nerelerden ulaşabileceği ve bu alana dair yapılan çalışmaların genel olarak eğilimini inceleyen bir çalışmaya ihtiyaç olduğu düşünülmüştür. Bundan dolayı çalışmanın sonuçlarının imalat sektöründe çeşitli alanındaki çalışmalara ve uygulamalara katkı sağlayacağı öngörülmektedir. Bu çalışmanın amacı, inconel 718 alaşımının işlenebilirliği ile ilgili akademik eserleri tarayarak sonuçları bibliyometrik analiz yöntemiyle sunmaktır.

YÖNTEM

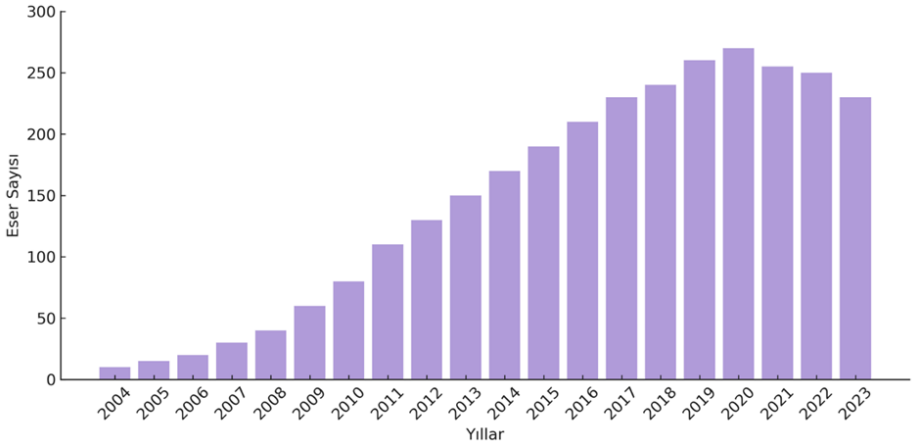
Sayısal veriler ve sayısal ölçüm göstergeleri kullanılarak gerçekleştirilen bibliyometrik analizlerle, inconel 718 alaşımının işlenebilirliği ile ilgili araştırmaların kapsamlı bir perspektifle araştırmacılara sunulması hedeflenmektedir.

29.11.2024 tarihinde, “inconel 718” ve “machining” anahtar kelimeleriyle “all fields” arama yapıldığında, sonuç olarak 2546 adet veri elde edilmiştir. Yıllara göre inceleme yapıldığında 1981 yılından 2024 yılına kadar, bu konuda birçok farklı kategoriden 1890 makale, 588 bildiri, ve 14 kitap bölümüne erişim sağlanmıştır. Veri tabanı olarak Web of Science (WoS)’ da yer alan veriler esas alınmıştır. Elde edilen verilerin, yıl ve WoS kategori analizi için WoS; işleme türlerinin analizi için WoS ve Microsoft Excel; anahtar sözcük, yazar, atıf, ülke, kurum, kaynak ve bibliyografik eşleşmeleri bakımından analizi için ise VOSviewer uygulamasından yararlanılmıştır.

BULGULAR

Yayınların Yıllara Göre Analizi

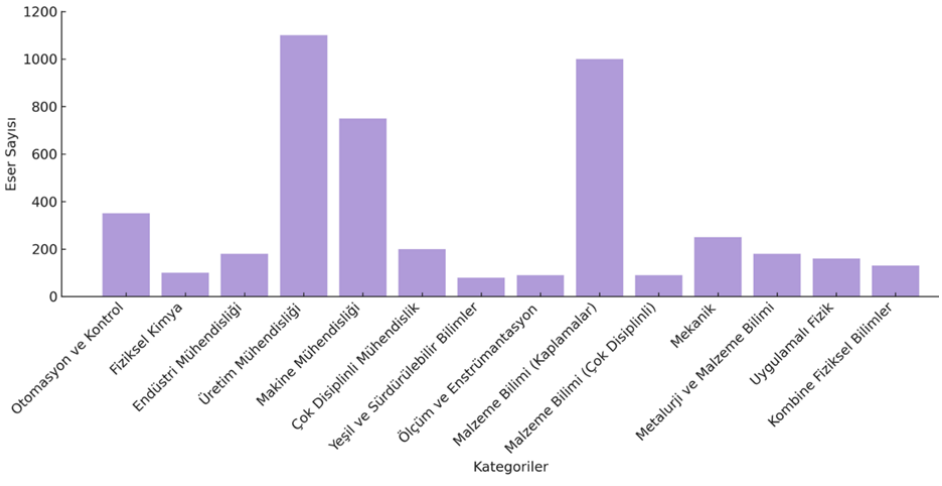
Inconel 718 alaşımının işlenebilirliği ile ilgili eserlerin yayınlanma süreçleri ilk olarak 1980’li yıllarda başlamıştır. 1981 yılından 2024 yılına kadar, minimum 10 eserin yayınlanmış olması kriterine göre filtreleme uygulandığında, her yıl yayınlanan eserlerin sayısı Şekil 1’ de sütun grafiği ile gösterilmiştir. 2015 yılından itibaren ciddi bir artış gösteren yıllık yayın sayısının 2022 yılında 273 adet yayın ile en fazla yayın yapılan yıl olduğu gözlenmektedir.



Şekil 1. Yıllara göre yayınlanan eserlerin analizi

Yayınların Farklı WoS Kategorilerine Göre Analizi

Inconel 718 alaşımının işlenebilirliği konusunda yayınlanan eserler, minimum eser sayısı 50 olarak seçildiğinde, Şekil 2’ de bulunan grafikte görüldüğü üzere birçok farklı WoS kategorisi içerisinde yer almaktadır.

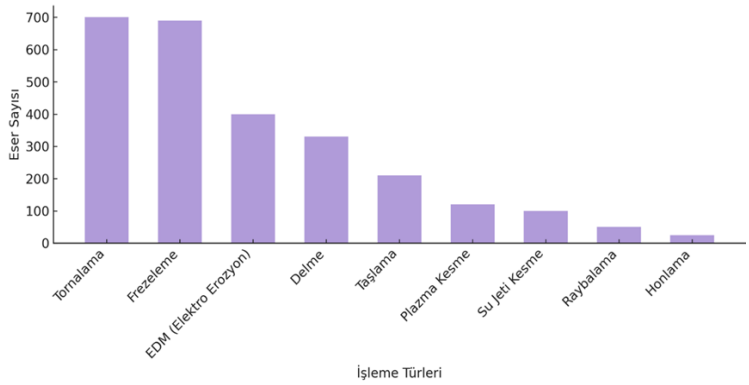


Şekil 2. Yayınların farklı kategorilere göre analizi

1134 (%44.5) adet yayın ile engineering manufacturing (üretim mühendisliği), 908 (%35.7) adet yayın ile materials science multidisciplinary (çok disiplinli malzeme bilimi), 762 (%29.9) adet yayın ile engineering mechanical (mekanik mühendisliği) konularının bu alanda önde gelen kategoriler olduğu görülmüştür.

Yayınların İşleme Türlerine Göre Analizi

WoS üzerinden "inconel 718" ve "machining" anahtar kelimelerine ek olarak "turning" (tornalama), "milling" (frezeleme), "electrical discharge machining -EDM" (elektro erozyon işleme) gibi yaygın metal işleme türleri eklenerek, "all fields" seçimi ile arama yapıldığında, elde edilen yayın sayıları ile Şekil 3'te yer alan grafik oluşturulmuştur.

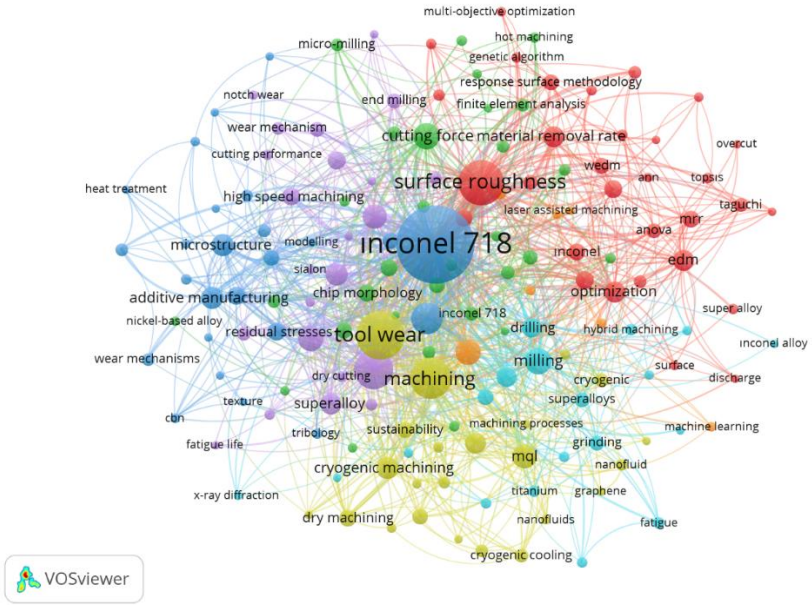


Şekil 3. Yayınların işlenebilirlik türlerine göre analizi

Yayınlarda en çok konu olarak ele alınan yöntemlerin 691 yayın ile tornalama, 623 yayın ile frezeleme ve 333 yayın ile EDM yöntemleri olduğu tespit edilmiştir.

Anahtar Sözcük Analizi

Inconel 718 alaşımının işlenebilirliği ile ilgili yayınlarda en sık kullanılan anahtar sözcüklerin incelenmesi için uygun kriterler ile filtreleme yapılmıştır. En az 10 kez tekrar eden anahtar sözcükler filtrelendiğinde 4456 kelimeden aralarında yoğun olarak ilişki bulunan 158 adet anahtar sözcük tespit edilmiştir. Bu 158 gözlem birimine odaklanılarak gerçekleştirilen analiz sonucunda 7 grup, 2608 ağ ve 6723 ağ gücü belirlenmiştir.

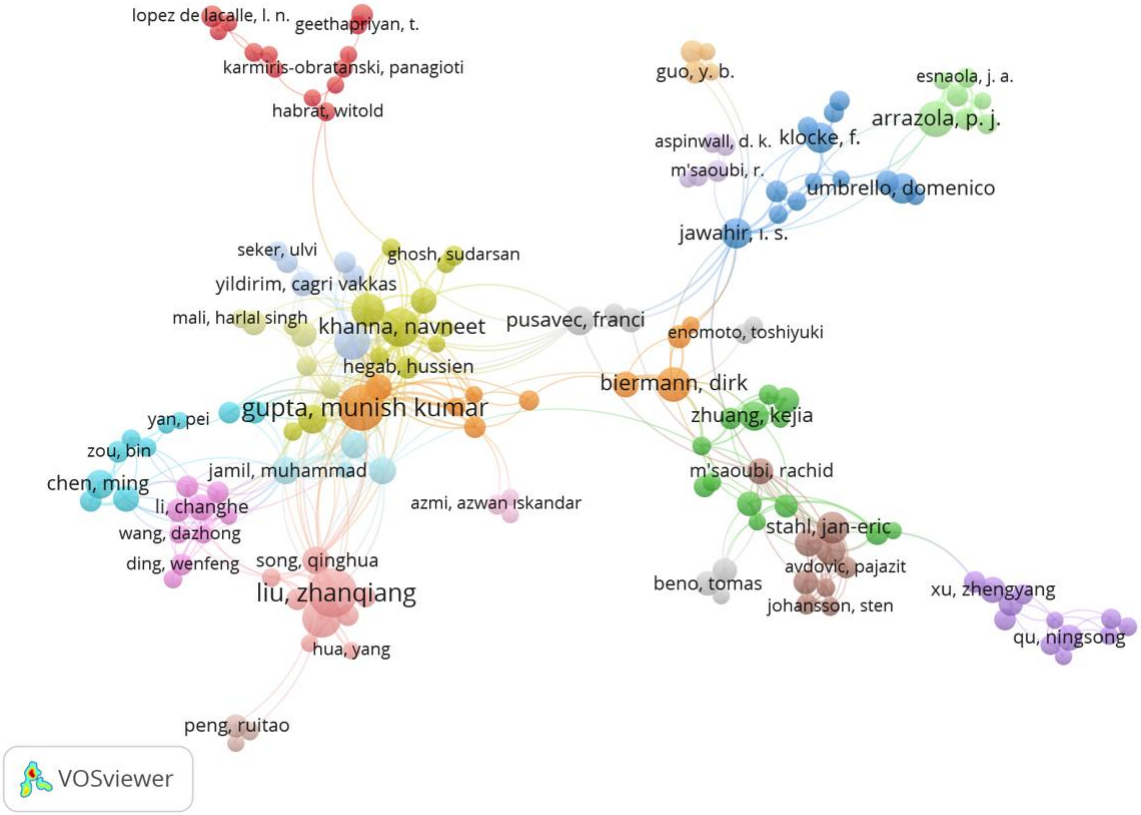


Şekil 4. En fazla kullanılan anahtar sözcüklerin haritası

Veri sonuçlarına bakıldığında 802 adet ile "inconel 718", 315 adet ile "tool wear" (takım aşınması), 276 adet ile "surface roughness" (yüzey pürüzlülüğü), 228 adet ile "machining" (işleme) ve 202 adet ile "surface integrity" (yüzey bütünlüğü) ifadeleri öne çıkan sözcüklerdir. Ağ gücü açısından da en güçlü ilk beş sözcüğün aynı sıralama ile geçerli olduğu gözlemlenmiştir.

Ortak Yazar Analizi

Ortak yazar analizine göre, en çok iş birliği kuran yazarları belirlemek üzere, 6255 yazardan minimum 5 eser ve minimum 5 atıf kriterleri seçilerek bağlantı haritasının görseli meydana getirilmiştir. Belirlenen kriterleri sağlayan 312 yazar arasından en fazla iş birliği yapan 156 yazarın ağ haritası oluşturulmuştur (Şekil 5). Bu 156 yazarın oluşturduğu birimler ile yapılan analiz sonucunda 21 grup, 474 ağ ve 1324 ağ gücü belirlenmiştir.

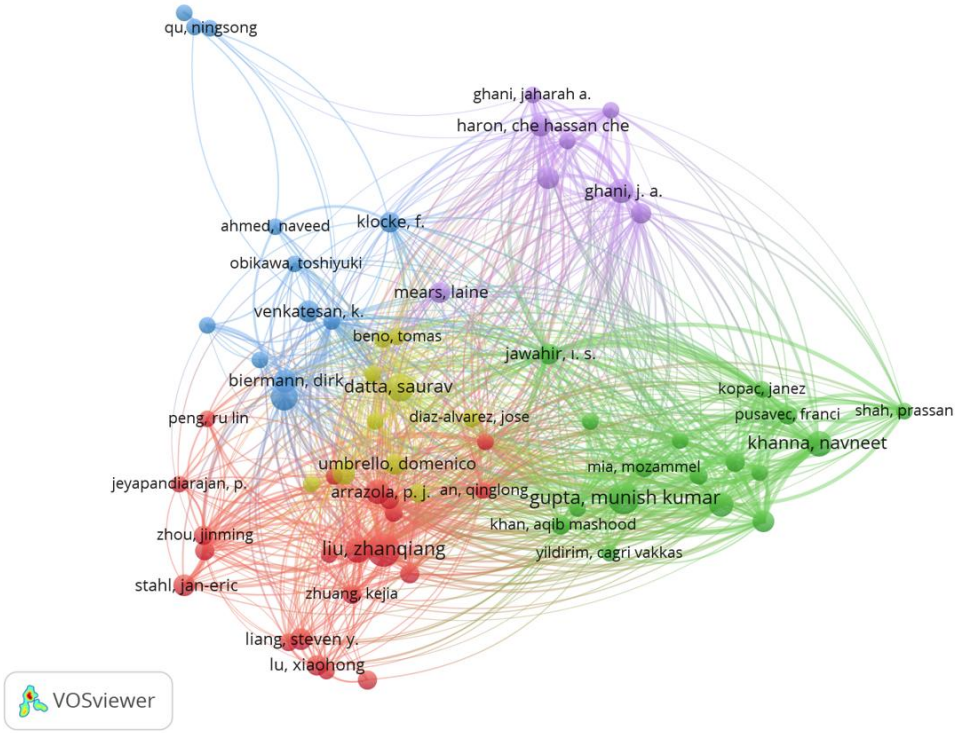


Şekil 5. Ortak yazar iş birliği analizi

En çok yayın üreten yazarlar arasında da 41 yayın ile Zhanqiang Liu, 36 yayın ile Munish Kumar Grupta ve 30 yayın ile Saurav Datta ilk üçte yer almaktadır. Munish Kumar Grupta, Zhanqiang Liu ve Navneet Khanna'nın ise en çok iş birliği kuran yazarların arasında olduğu gözlemlenmiştir.

Yazar Atıf Analizi

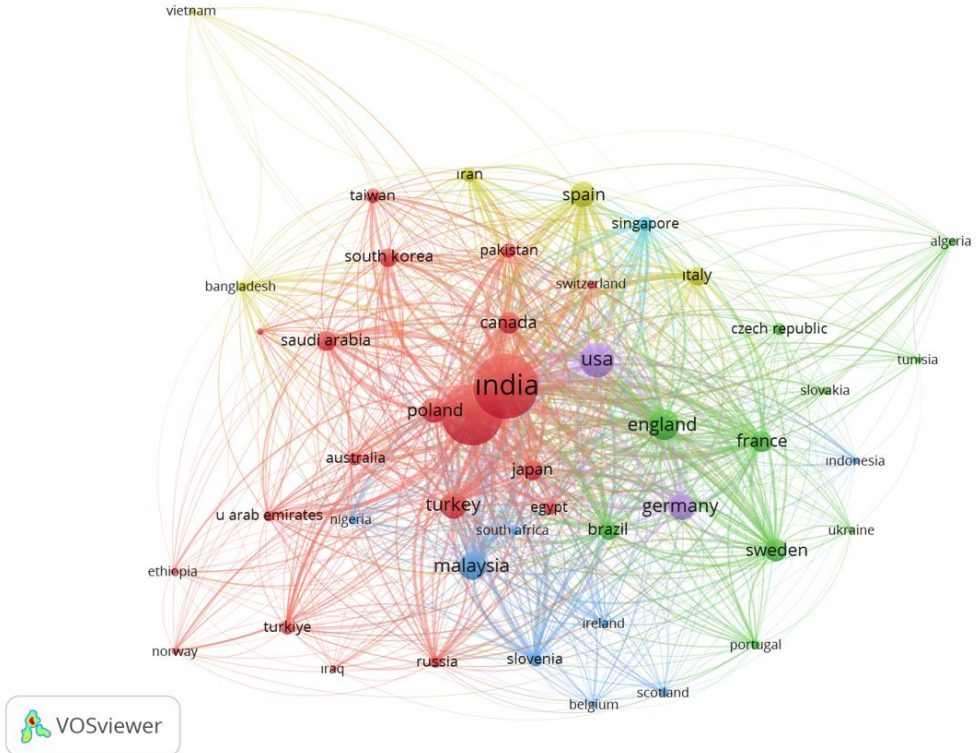
Atıf bağlantılarını belirleyebilmek için minimum 10 eser ve minimum 10 atıf kriterleri ile bir bağlantı haritası oluşturulmuştur. Aralarında sık bağlantı olduğu tespit edilen 68 unsur ile oluşturulan analiz sonucunda 5 grup, 1155 ağ ve 4999 ağ gücü olduğu belirlenmiştir. Maksimum atıf sayısına sahip olan yazarlar 1840 atıf ile Murat Sarıkaya, 1601 atıf ile Munish Kumar Grupta ve 1583 atıf ile I.S. Jawahir olarak tespit edilmiştir.



Şekil 6. Yazarların atıf analizi

Ülke Atıf Analizi

Toplam 79 ülkeden yayınlanan eserlerin ülkeleri, aldıkları atıf sayıları bakımından ağ analizi haritası meydana getirmek üzere, herhangi bir ülkenin minimum 5 eser ve minimum 5 atıf kriterlerini sağlamasına göre birbiriyle iş birliği kurulan 46 adet ülkenin gözlem birimini oluşturduğu, Şekil 7'de bulunan haritaya göre değerlendirme gerçekleştirilmiştir. 6 grup, 829 ağ ve 24377 ağ gücü olduğu belirlenmiştir.

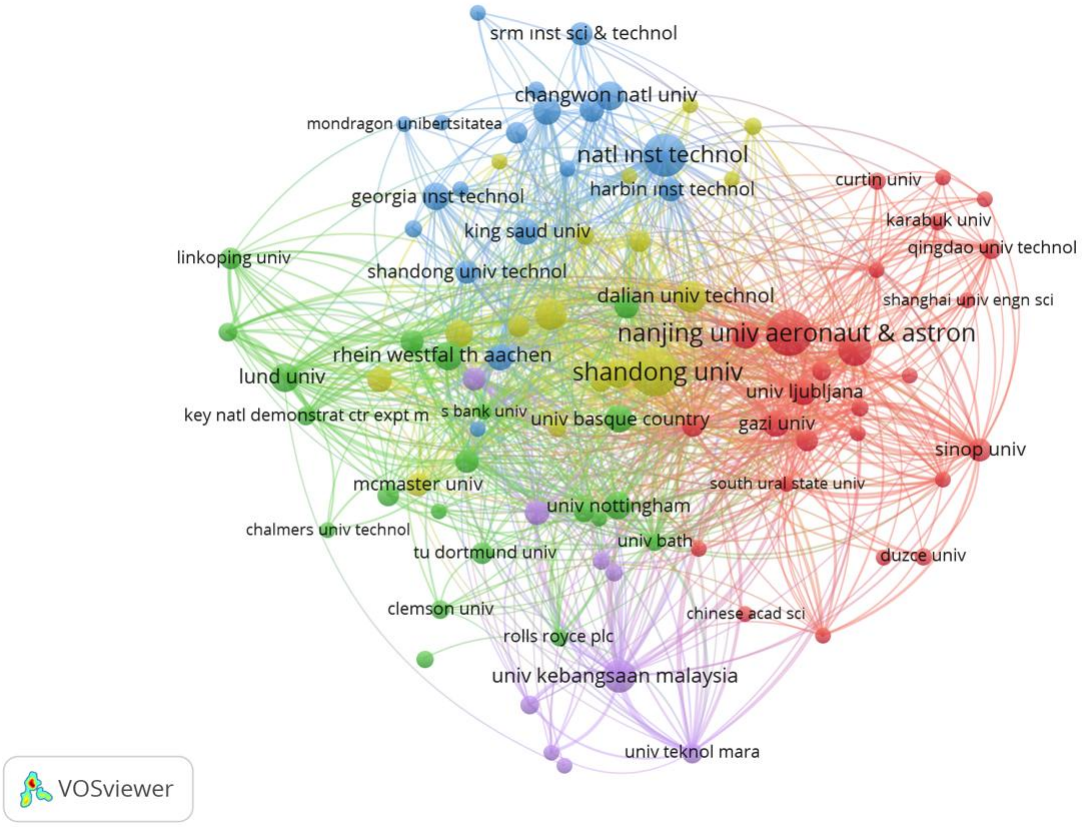


Şekil 7. Ülkelerin atıf ağ analizi

En fazla yayın yapan ülkelerden 681 yayın ile Hindistan, 610 yayın ile Çin ve yine 193 yayın ile ABD önde gelen ülkeler olduğu görülmüştür. Atıf sayısı açısından da bu ülkelerin aynı sıralama ile ilk üç sırada yer aldığı gözlemlenmiştir. Ağ gücü bakımından ise, Hindistan, Çin ve İngiltere güçlü ülkeler arasında olmuştur.

Kurum Atıf Analizi

Eserlerin yayınlandığı kurumların aldığı atıflara ait bir haritasını oluşturabilmek için toplam 1853 kurum arasından en az 10 yayında yer alan ve en az 10 atıf almış olan kurumlar için filtreleme uygulandığında 92 adet kurumun seçildiği bu kriterleri sağladığı saptanmıştır. Şekil 8, yoğun olarak iş birliği içerisinde olan ve en az 10 yayında yer alan 91 adet kurumun haritası gösterilmektedir. 5 grup, 2658 ağ ve 11482 ağ gücü belirlenmiştir.

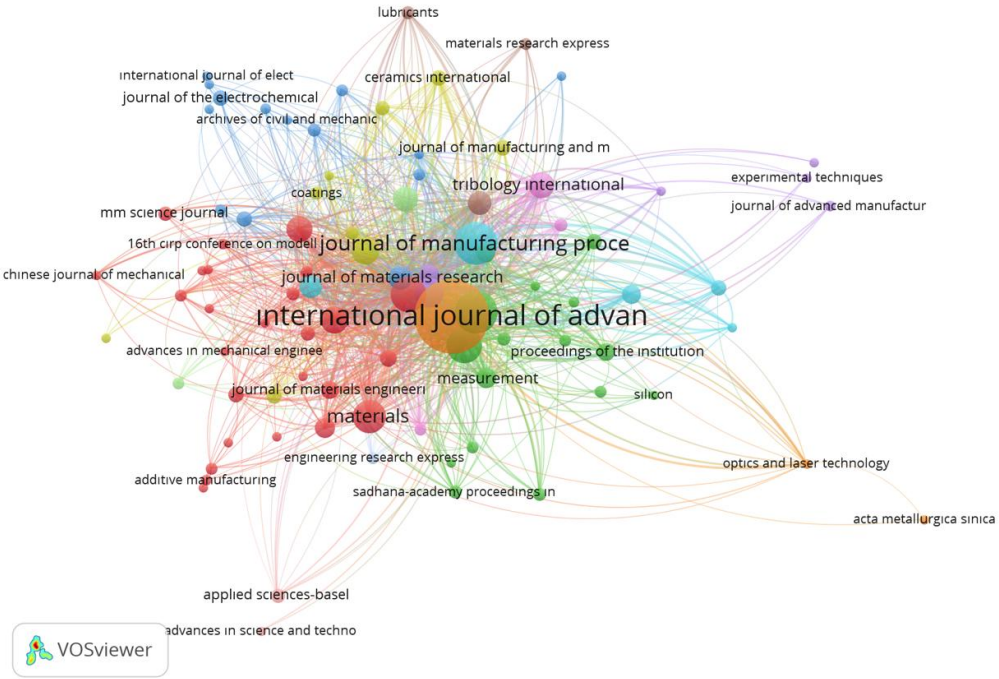


Şekil 8. Kurumların atıf ağ analizi

En fazla yayın yapan kurumlar arasında, 95 eser ile Shandong University, 86 eser ile Nanjing University of Aeronautics and Astronautics ve 73 eser ile National Institute of Technology önde gelen kurumlardır. En çok atıf alan kurumlardan ise, 3043 atıf ile Shandong University, 2575 atıf ile Nanjing University of Aeronautics and Astronautics ve 1858 atıf ile Indian Institutes of Technology kurumları ilk sıralarda yer almıştır.

Eserlerin Kaynak Analizi

Eserlerin yayınlandığı kaynakların aldığı atıflara ait bir haritasını oluşturabilmek için toplam 583 kaynak arasından minimum 5 eser içeren ve minimum 5 atıf almış olan kaynaklar için filtreleme uygulandığında 90 adet derginin seçildiği bu kriterleri sağladığı saptanmıştır. Şekil 9, yoğun olarak iş birliği içerisinde olan ve en az 5 yayın yapılmış olan 90 adet kurumun haritası gösterilmektedir. 12 grup, 1456 ağ ve 9474 ağ gücü olduğu gözlemlenmiştir.

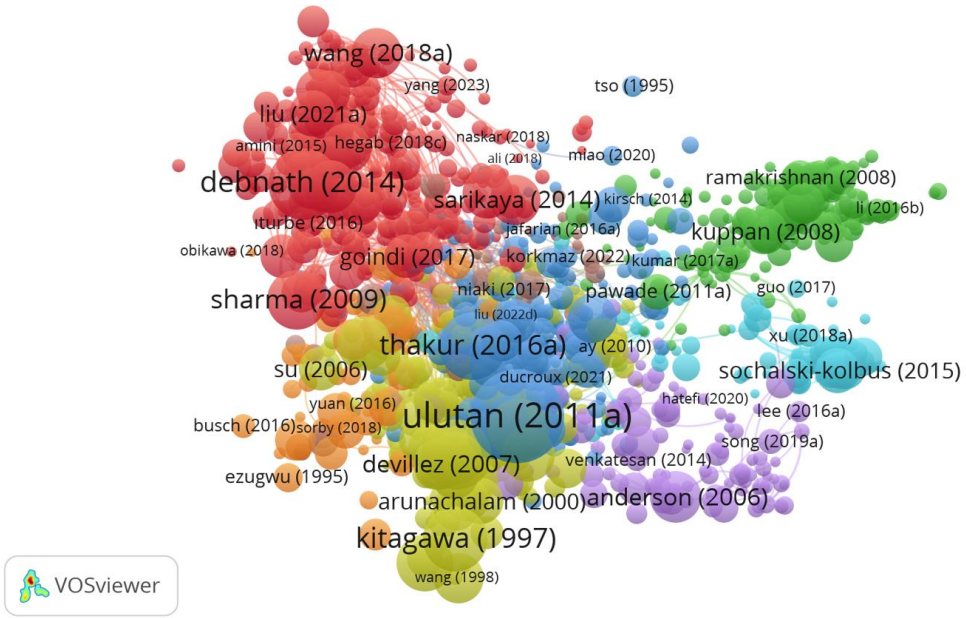


Şekil 9. Eserlerin yayınlandığı kaynakların analizi

En fazla yayın yapan kaynakların, 313 adet yayın ile "international journal of advanced manufacturing technology", 103 adet yayın ile "materials today-proceedings" ve 102 adet yayın ile "journal of manufacturing processes" adlı kaynaklar olduğu tespit edilmiştir.

Eserlerin Bibliyografik Eşleşme Analizi

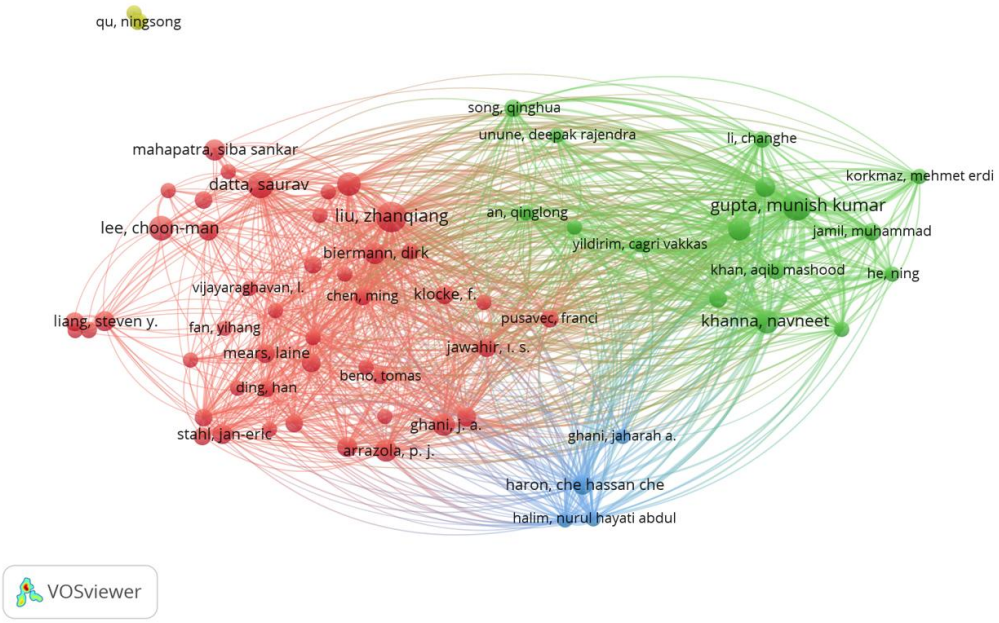
Bibliyografik eşleşme, bağımsız iki kaynağın ortak bir çalışmayı referans göstermesi durumunu tanımlar. Minimum 10 atıf alma kriteri ile filtrelenen ve birbiriyle ağı olan 1316 eser ile oluşturulan analizin sonucunda 9 grup, 150678 ağ ve 285672 ağ gücü olduğu gözlemlenmiştir. Maksimum sayıda bibliyografik eşleşmeye sahip olan eserler 932 atıf ile Ulutan (2011a), 551 atıf ile Debnath (2014) ve 518 atıf ile Dudzinski (2004) olduğu belirlenmiştir. Maksimum ağ gücüne sahip eserler ise De bartolomeis (2021b), Thakur (2016a) ve Paturi (2021b) olmuştur.



Şekil 10. Eserlerin bibliyografik eşleşme analizi

Yazarların Bibliyografik Eşleşme Analizi

Minimum 10 yayın yapmış olma ve minimum 10 atıf alma kriterleri ile belirlenen ve birbirleriyle bağlantısı olan 68 yazar ile gerçekleştirilen analiz sonucunda göre 4 grup, 2237 ağ ve 287328 ağ gücü gözlemlenmiştir.

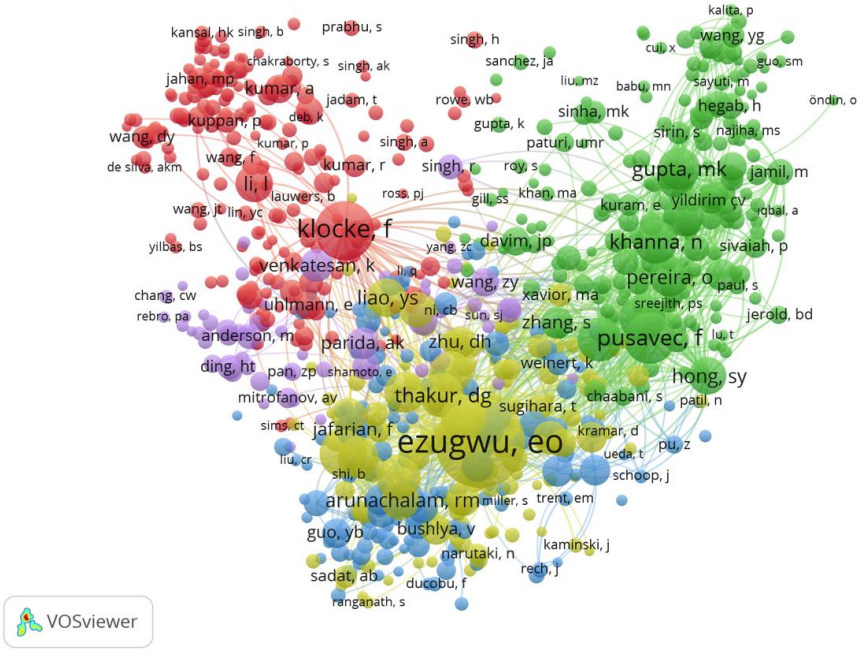


Şekil 11. Yazarların bibliyografik eşleşme analizi

En fazla sayıda bibliyografik eşleşme olan yazarların 1840 atıf ile Murat Sarıkaya, 1601 atıf ile Munish Kumar Grupta ve 1583 atıf ile I.S. Jawahir olduğu görülmüştür.

Yazarların Eş atıf Analizi

Bir yayına atıfta bulunulan çeşitli eserler, eş atıf (co-citation) olarak isimlendirilir. En az 20 adet atıf alma ile filtrelenerek 793 unsur ile oluşturulan analiz sonucunda 5 grup, 140754 ağ ve 730687 ağ gücü gözlemlenmiştir. En çok eş atıf gösterilen yazarlar E.O. Ezugwu (1349), F. Klocke (576) ve F. Pusavec (435) olarak tespit edilmiştir.



Şekil 12. Yazarların eş atıf analizi

SONUÇ

Çalışma kapsamında WoS veri tabanında inconel 718 alaşımının işlenebilirliği üzerine yayınlanan akademik yayınların günümüze kadar olan gelişim süreci incelenmiştir. Belirlenen kriterler aralığında ilgili kavramları içeren yayınlar zamana göre incelendiğinde, inconel 718 alaşımının işlenebilirliği alanında yapılan ilk yayınının 1981 yılında yapıldığı görülmüştür. Araştırma kapsamında inconel 718 alaşımının işlenebilirliği ile ilgili en fazla yayının 2022 yılında yapıldığı tespit edilmiştir. 1981 yılından bu yana yayın sayısında değişkenlik görülmekle birlikte genel eğilimin son yıllarda artış olduğu gözlemlenmektedir. Ek olarak, yayınlanan eserler konuları bakımından sınıflandırıldığında, çoğunun üretim mühendisliği ve multidisipliner malzeme bilimi kategorisinde yer aldığı görülmüştür. Bu da, konuyla ilgili eserlerin hem havacılık, savunma, medikal ve otomotiv gibi üretim alanlarında, hem de kimya, mekanik, dayanıklılık ve performans gibi mühendislik alanlarının gelişmesinin sonucudur. Mevcut yayınlarda, inconel 718 alaşımınının işleme türlerinden en çok tornalama ve frezeleme işlemlerinin konu olarak ele alındığı görülmüştür.

Inconel 718 alaşımınının işlenebilirliğini içeren eserler incelendiğinde inconel 718, takım aşınması ve yüzey pürüzlülüğü terimlerinin yoğun olarak kullanıldığı tespit edilmiştir. Bu terimlere ek olarak; işleme ve yüzey bütünlüğü gibi terimler de bu alanda yayınlanan makalelerde önde gelen terimler arasında yer almaktadır. Inconel 718 işlenebilirlik uygulamaları üzerinde; Hindistan, Çin, ABD, İngiltere, Malezya, Almanya ve Türkiye başta olmak üzere dünyada birçok ülkede çalışılmaktadır. Zhanqiang Liu, Munish Kumar Grupta ve Saurav Datta gibi bu alanda en çok yayın yapan bilim insanlarının da bu ülkelerden olduğu görülmüştür. Shandong University, Nanjing University of Aeronautics and Astronautics ve National Institute of Technology bu konuyla ilgili en çok akademik yayının da yine bu ülkelerin kuruluşlarında yapıldığını göstermektedir.

Bu araştırmadan elde edilen diğer bir sonuç ise, 1092 adet atıf ile en fazla atıf sayına sahip "Machining induced surface integrity in titanium and nickel alloys: A review" (Titanyum ve nikel alaşımlarında işleme kaynaklı yüzey bütünlüğü: Bir inceleme) adlı akademik makalenin Rutgers Universitesi, Endüstri ve Sistem Mühendisliği öğretim üyeleri olan Durul Ulutan ve Tuğrul Özel tarafından yazılmıştır. Makalenin içeriğinde; titanyum ve nikel alaşımlarında işleme kaynaklı yüzey bütünlüğü sorunları ele alınarak, bu sorunların kalıntı gerilimler, yüzey değişikliği ve mikro yapısal değişiklikler gibi faktörlerden kaynaklandığı tespit edilmiş ve yüzey kalitesini etkileyen kesme hızı, ilerleme hızı, kesme derinliği, takım geometrisi ve aşınması gibi parametrelerin önemine dikkat çekilmiştir. Ayrıca, mevcut modelleme yaklaşımlarının eksikliği vurgulanarak, endüstriyel uygulamalara uygun modellerin geliştirilmesi gerektiği sonucuna ulaşılmıştır [6].

Araştırma kapsamında, Inconel 718 alaşımınının işlenebilirliği konusunda yayınlanan eserlerin genel olarak incelenmesini görselleştirmek için yapılan bu çalışmanın; konuyla ilgili çalışma yapmak isteyen araştırmacılar için litaratür taraması öncesinde yol gösterici bir doküman olarak rehberlik sağlayarak yardımcı olacağı düşünülmektedir. Bu konu ile ilgilenen ve çalışma yapmayı planlayan araştırmacıların, konuyla ilgili en fazla yayın yapan dergileri ve yazarların eserlerini incelemeleri ve en fazla atıf alan eserleri gözden geçirmeleri önerilebilir. Bu incelemelerin yapılması durumunda araştırmacıların konuyla ilgili geçmişten günümüze kadar olan gelişmelerin eğilimi hakkında genel bir bilgiye sahip olacağı düşünülmektedir.

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PUNICA GRANATUM (POMEGRANATE) PEEL EXTRACT MEDIATED GREEN SYNTHESIS AND CHARACTERIZATION OF MAGNETIC SPINEL COPPER FERRITE ($CuFe_2O_4$): SONO FENTON-LIKE DECOLORIZATION OF REACTIVE RED 2

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ABSTRACT
In this study, magnetic spinel copper ferrite ($CuFe_2O_4$) was synthesized by the green synthesis approach using ethanolic extract of *Punica granatum* (pomegranate) peel, a food waste material. Characterization studies of $CuFe_2O_4$ were carried out by FT-IR, XRD, and SEM-EDX analyses. The $CuFe_2O_4$ was utilized as a heterogeneous catalyst for Reactive Red 2 (RR 2) removal from aqueous solutions by the sono-Fenton-like reaction. In characterization studies, the two significant absorption bands were observed in the FT-IR spectrum of $CuFe_2O_4$. The bands at 434.70 cm^{-1} and 531.88 cm^{-1} are attributed to the intrinsic lattice stresses of Cu–O strain bonds at the tetrahedral end, and Fe–O strain bonds at the octahedral shell, respectively. In the XRD spectrum, the diffraction peak positions and relative intensities exactly match well with the standard powder diffraction data reference (JCPDS card no: 34–0425) of the inverse spinel tetragonal structure for $CuFe_2O_4$. SEM images showed $CuFe_2O_4$ particles have a polyhedra morphology. According to EDX analysis results, there were 2.39% C, 26.96 % O, 46 % Fe, 24 % Cu, 0.27 % S, and 0.41% Ca in the chemical structure of $CuFe_2O_4$, which confirmed the successful synthesis of the catalyst. Trace amounts of Ca and S elements were thought to originate from pomegranate peel extract. Synthesized magnetic spinel $CuFe_2O_4$ was tested as a catalyst in the sono Fenton-like decolorization of RR 2 textile dye. In the experimental studies, nearly 95% color removal was achieved after 90 min reaction time under an initial pH of 3.0, a catalyst concentration of 1 g/L, H_2O_2 concentrations of 500 mM, temperature of 25°C experimental conditions for 100 mg/L of RR 2 dye concentration by applying ultrasonic frequency and power.

Keywords: Sono Fenton-like process, $CuFe_2O_4$, Green synthesis, Heterogeneous catalyst, Pomegranate peel.

INTRODUCTION

Currently, water pollution is one of the most significant environmental issues. The textile industry has been known as a significant contributor to the contamination of surface and underground water. The discharge of dyes into natural streams may be toxic to aquatic life due to the presence of metals and chlorides (Benkhaya et al., 2022; Ramos et al., 2021). Furthermore, even minute quantities of dyes in water (less than 1 ppm for certain dyes) are highly visible and undesirable for any use. Therefore, it is necessary to effectively, practically, and cost-efficiently remove wastewater containing textile pollutants in a manner that meets wastewater discharge standards (Asghar et al., 2015).

Recently, considerable attention has been directed towards advanced oxidation processes (AOPs) such as Fenton, Fenton-like, electro-Fenton, photo-Fenton, ozonation, electrochemical oxidation, photolysis with H_2O_2 and O_3, and UV/H_2O_2, etc. These processes have garnered significant interest for the treatment of toxic and carcinogenic organic and inorganic pollutants from water sources. The degradation mechanism of these processes is based on the production and the oxidative action of hydroxyl radicals (Kanakaraju et al., 2018).

Sonolysis, also called ultrasound (US) irradiation, is one of the advanced oxidation methods. Specifically, the combination of US and oxidizing agents has been demonstrated to significantly enhance reactive oxygen species (ROS) generation. Consequently, there has been a recent surge of interest in the combination of the Fenton process and sonolysis, which is referred to as sono Fenton. The conversion of H_2O_2 to OH• is significantly accelerated by ultrasound due to the enhanced reactivity of the species involved. Moreover, it is generally accepted that cavity bubbles are responsible for destroying O-H bonds and the formation of OH• radicals. The result of this process is the formation of strong shear fields, which are the result of the collapse of cavity bubbles (J.-H. Chu et al., 2021; Feng et al., 2016).

In recent years, spinel ferrites (expressed as MFe_2O_4, where M = Mn, Co, Ni, Cu, Mg, etc.) have emerged as preferred magnetic materials in catalytic processes, owing to their comparatively high abundance, cost-effectiveness, and easy separation from aqueous solution under the influence of a magnetic field. The spinel ferrites have considerable potential as adsorbents and photocatalysts for treating contaminated water (Ding et al., 2021). As one kind of spinel, copper ferrite ($CuFe_2O_4$), which contains both Cu(II) and Fe(III) in different crystallographic sites, resulting in enhanced stability (Feng et al., 2016). $CuFe_2O_4$ has been utilized extensively in the field of heterogeneous catalysis for the reactions of peroxymonosulfate (PMS), peroxydisulfate (PDS), and H_2O_2 (Saemian et al., 2022).

The biosynthetic approach has been extensively preferred in recent years for the synthesis of metal and metal oxide particles in the area of catalysis. The procedure involves the use of extracts from various biological sources instead of inorganic bases for the synthesis of metal/metal oxide particles (Roy et al., 2021). The green synthesis process utilizes plants, microbes, bio-polymers, and solid wastes for the active biocomponent, along with the low temperature requirement and environmentally friendly solvents (Bolade et al., 2020).

The peel of the pomegranate fruit constitutes approximately 40 – 50% of the total fruit weight. It is a particularly rich source of phenolic compounds, including flavonoids, phenolic acids, tannins, proteins, bioactive peptides, and polysaccharides (Khalo & Ramazanoğlu, 2023). Therefore, pomegranate peel extract can be a good reducing agent for the green synthesis of metal/metal oxide materials. Moreover, their environmental impact can also be reduced in this way.

In this study, food-waste-derived $CuFe_2O_4$ particles were synthesized by using the ethanolic extract of *Punica granatum L.* (pomegranate) peel as a bioreductant agent. The material was characterized by FT-IR, XRD, and SEM-EDX analyses. Then, the effective

usability of $CuFe_2O_4$ as a heterogeneous catalyst was investigated for Reactive Red 2 (RR 2) remediation from aqueous solutions by the sono-Fenton-like reaction.

MATERIAL AND METHODS

Materials

All chemicals used in experiments were of analytical grade and were used as received without any further purification. $Fe(NO_3)_3.9H_2O$ and $Cu(NO_3)_2.3H_2O$ metal salts, and Reactive Red 2 (RR 2) were supplied by Sigma-Aldrich. RR 2 was of commercial purity ($C_{19}H_{10}Cl_2N_6Na_2O_7S_2$, Type: Anionic, Mw: 615.33 g.mol^{-1}, λmax: 538 nm). Its chemical structure is shown in Figure 1 (Ergüt & Özer, 2019).

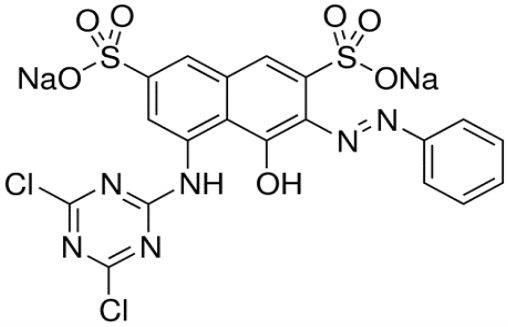

Figure 1. Chemical structure of Reactive Red 2

Methods

Preparation of pomegranate peels

The pomegranate fruit used in the study was obtained from local markets. After domestic consumption, the pomegranate peels were rinsed with tap water and cut into thin slices. Then, the peels were thoroughly cleaned with deionized water and dried in an oven at 60°C for 72 h. The dried pomegranate peels were ground into powder using a coffee grinder.

Preparation of pomegranate peel extract

Pomegranate peel extract was prepared using the solvent extraction method with 100% ethanol. After adding ethanol to an appropriate amount of pomegranate peel powder (10% w/v), the mouths of the beakers were covered with parafilm. The beakers were placed in a water bath and shaken at 25°C for 72 h at 100 rpm stirring speed. Then, the mixture was filtered to separate the liquid (extract) and solid phases (pomegranate peel powder). The obtained ethanolic extract was stored in the refrigerator at +4°C (Ravikumar et al., 2019).

Green synthesis of magnetic spinel copper ferrite ($CuFe_2O_4$) particles

0.1 M $Fe(NO_3)_3.9H_2O$ and 0.05 M $Cu(NO_3)_2.3H_2O$ metal salts were dissolved in 50 mL of distilled water and then stirred at 500 rpm- 30°C. Afterward, pomegranate peel ethanolic extract was added dropwise to the solution with a Pasteur pipette at a volume ratio of 1:1 (v/v), and the solution was continued to stir. After the ethanolic extract was added, the color of the metal salt solution changed from yellow to black over time, indicating the formation of copper ferrite particles. The final solution was magnetically stirred at 30°C for 3 h. There is no pH adjustment carried out throughout the procedure. The mixed solution was dried in a hot air oven at 80°C for many hours. The powder was ground and then sintered at 1000°C for three hours in a muffle furnace (Kombaiah et al., 2018).

Characterization studies

Functional groups were determined by FT-IR analysis in the range of 400 – 4000 cm^{-1} using a Bruker brand FT-IR device. The crystal structure of the material was determined by XRD analysis using nickel-filtered Cu Kα radiation in a Rigaku Miniflex 600 brand device at 40 kV and 15 mA, 2θ=10°–90° conditions. The morphological properties of the synthesized

$CuFe_2O_4$ powder were determined by a TESCAN MIRA3 XMU model SEM, and the elemental composition was determined by a TESCAN MIRA3 XMU model EDX device.

Heterogeneous sono Fenton-like decolorization experiments of Reactive Red 2

Sono Fenton-like activity of $CuFe_2O_4$ particles was examined by evaluating the decolorization of organic Reactive Red 2 (RR 2) dye aqueous solution. The sono Fenton-like experiments were carried out in the 250 mL Erlenmeyer flasks in an ultrasonic bath (Mikrotest, 500 W, 50 Hz). The temperature was kept constant at room temperature (25°C).

In the decolorization experiments, the desired amount of $CuFe_2O_4$ was added to solutions containing 50 mL of RR 2 solution at a known initial pH and initial dye concentration. 0.1 N HCl or 0.1 N NaOH solutions were used to set the initial pH of the solutions. Before initiating the sono Fenton-like experiments, the flasks were kept in the ultrasonic bath for 2 min to ensure adsorption–desorption equilibrium of the dye solutions with the catalyst. Then, the heterogeneous sono Fenton-like experiment was started with the addition of 2 mL of H_2O_2 solution. The samples were collected at predetermined time intervals, and the catalyst was separated using an external magnet.

The concentration of RR 2 was analyzed with the Microplate spectrophotometer at an ultraviolet-visible (UV-vis) wavelength of 538 nm. The decolorization percentage for RR 2 was expressed in terms of the decrease in UV-vis absorbance and calculated with Equation (1) as given below.

$$CR(\%) = \frac{A_{0|538\ nm} - A_{t|538\ nm}}{A_{0|538\ nm}} x100 \qquad (1)$$

Where the color removal efficiency of the catalyst is represented by CR (%), A_o is the initial absorbance of RR 2 at t=0 min, and A_t is the measured absorbance of RR 2 at any reaction time (t) min.

RESULTS AND DISCUSSIONS

Characterization of $CuFe_2O_4$

Structural characterization of the green synthesized $CuFe_2O_4$ particles mediated by ethanolic extract of *Punica granatum L.* peel was carried out FT-IR, XRD, SEM, and EDX analyses. The magnetic property of $CuFe_2O_4$ was evaluated by an external magnet.

FT-IR analysis

The functional groups at the surface of the copper ferrite particles was analyzed by the FTIR measurement. The obtained FT-IR spectrum of $CuFe_2O_4$ particles is illustrated in Figure 2.

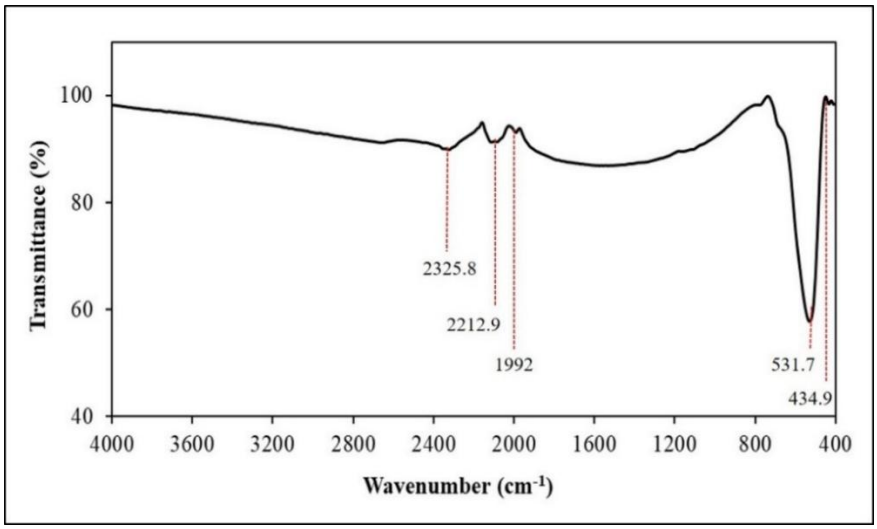

Figure 2. FT-IR analysis spectrum of $CuFe_2O_4$ particles

According to Figure 2, the small band at 2325.8 cm^{-1} confirms C–H chemical functional group. The synthesis of $CuFe_2O_4$ particles was confirmed by their bands in the fingerprint region, indicating the presence of metal oxide bondind linkages. Thus, the bands observed at 434.70 cm^{-1} and 531.88 cm^{-1} are attributed to the intrinsic lattice strains of the Cu-O bond at the tetrahedral site and the Fe-O bond at the octahedral shell, respectively (El Messaoudi et al., 2025).

XRD analysis

XRD analysis was conducted to determine phase formation, the crystal nature, and the purity of the $CuFe_2O_4$ particles. The XRD pattern of $CuFe_2O_4$ particles is presented in Figure 3.

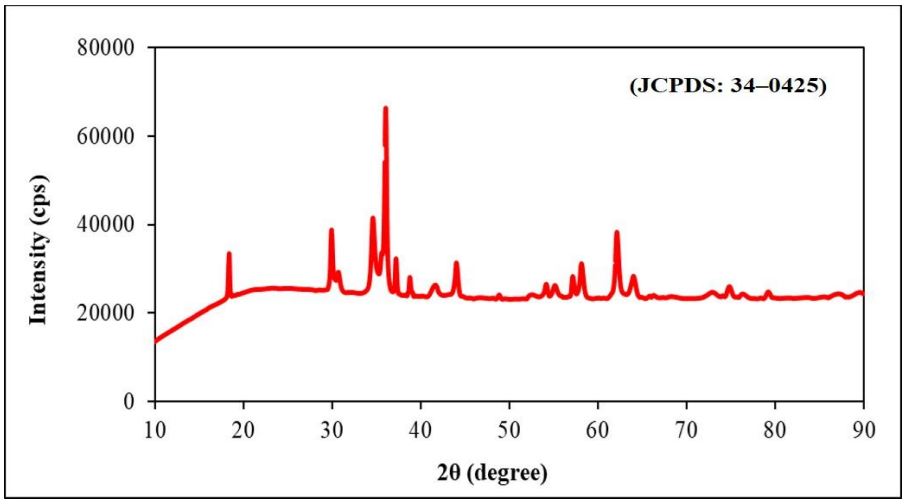

Figure 3. XRD pattern of $CuFe_2O_4$ particles

The location of the diffraction peaks and the relative intensity levels corresponded to the standard powder diffraction data reference (JCPDS card no. 34–0425) of the inverse spinel tetragonal structure for $CuFe_2O_4$. Accordingly, the peaks found at 2θ = 30.01° (200), 36.4° (211), 37.51° (202), 44° (220), 54° (312), 57° (303), 63 ° (224) corresponded to the cubic spinel structure of $CuFe_2O_4$ with no impurity phases (El Messaoudi et al., 2025; Samikannu et al., 2023).

SEM and EDX analysis

The morphology and surface structure of the $CuFe_2O_4$ particles were determined by SEM analysis. Figure 4 shows SEM micrographs of $CuFe_2O_4$ at different magnifications.

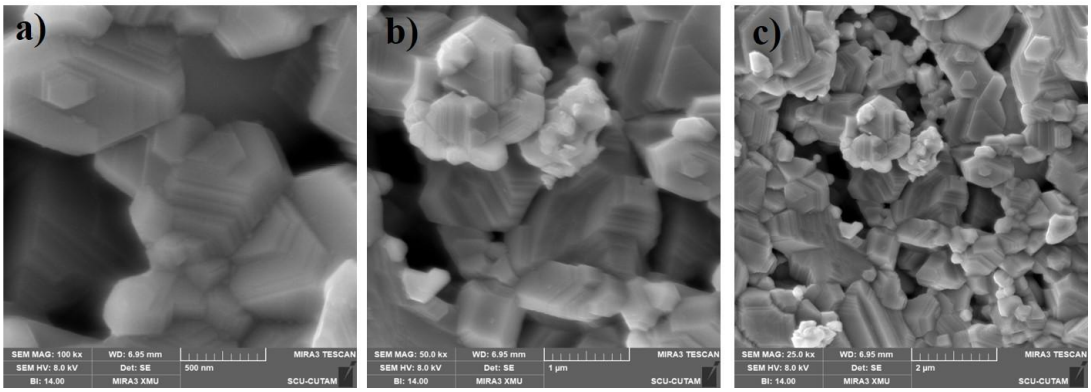

Figure 4. SEM images of $CuFe_2O_4$ at different magnifications a) 100 kx-500 nm b) 50 kx-1µm c) 25 kx-2µm

According to SEM micrographs, the particles appear as polyhedra with few agglomerations and negligible porosity.

The chemical composition of the synthesized material was determined by EDX analysis. Figure 5 shows the EDX spectrum of $CuFe_2O_4$ compound.

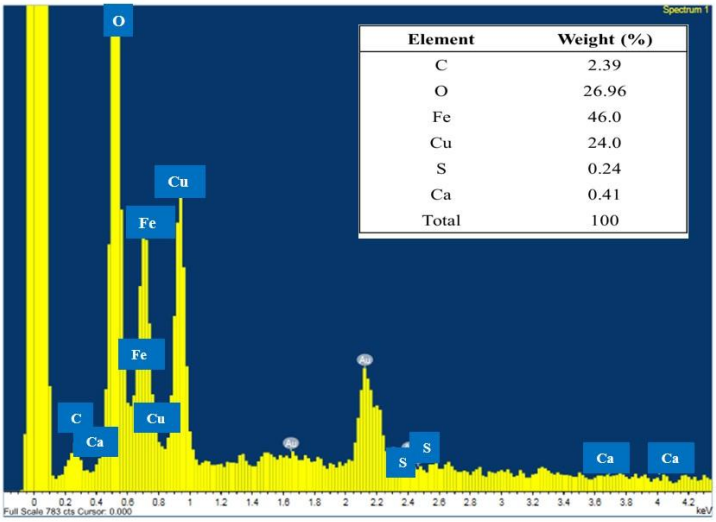

Figure 5. EDX spectrum of $CuFe_2O_4$

EDX analysis results revealed the presence of Cu, Fe, and O peaks, which are related to the $CuFe_2O_4$ particles. The quantitative weight composition of $CuFe_2O_4$ particles was composed of

2.39% C, 26.96 % O, 46 % Fe, 24 % Cu, 0.27 % S, and 0.41% Ca elements. Trace amounts of Ca and S elements were thought to originate from pomegranate peel ethanolic extract. Moreover, the Fe: Cu ratio was ≈ 2:1, which is consistent with theoretical calculations.

Magnetic property of $CuFe_2O_4$

The magnetic behaviour of green synthesized $CuFe_2O_4$ particles was observed with an external magnet. Figure 6 shows the magnetic behaviour of $CuFe_2O_4$.

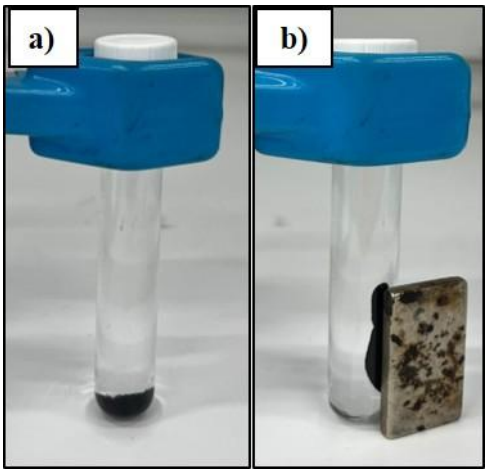

Figure 6. Magnetic behaviour of $CuFe_2O_4$: (a) $CuFe_2O_4$ in distilled water and (b) magnetic attraction of $CuFe_2O_4$ toward a magnet.

When an external magnet was held in an aqueous solution containing copper ferrite particles, the particles moved in the direction of the magnet (Figure 6(b)). Conversely, when

the magnet is removed, the $CuFe_2O_4$ particles are redispersed readily and precipitated in the aqueous medium (Figure 6 (a)). This shows that the $CuFe_2O_4$ particles can be easily separated from the aqueous solution owing to their magnetic properties.

Heterogeneous Sono Fenton-Like Decolorization of Reactive Red 2

The catalytic performance of the synthesized $CuFe_2O_4$ particles was examined in the heterogeneous sono Fenton-like decolorization of RR 2 dye. The pH effect on RR 2 decolorization was investigated in the range of pH 3.0 – 9.0. Decolorization efficiencies after 90 min are shown in Figure 7.

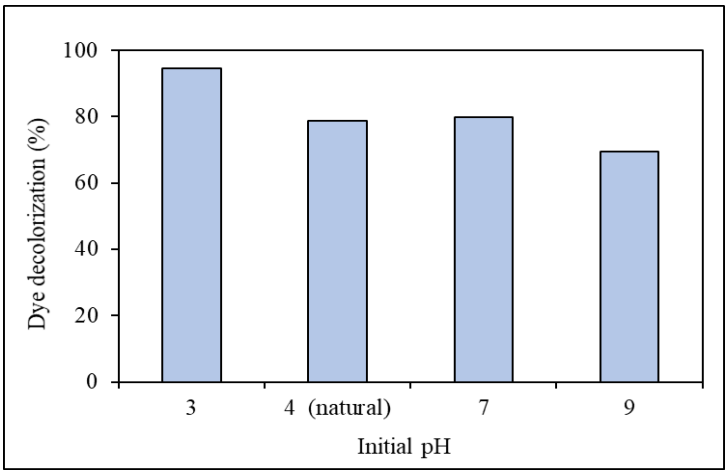

Figure 7. The initial pH effect on the decolorization of RR 2 (C_o=100 mg/L $C_{H_2O_2}$ = 500 mM, X_o=1 g/L, pH=3.0, T=298 K, US =50 Hz, 500 W)

The initial pH is critical to effective removal in Fenton-like processes. In the catalytic process, hydroxyl (OH•) radicals emerge as the predominant reactive species in acidic environments, while Fe (IV) assumes a primary role in neutral conditions. The initial pH has been demonstrated to induce metal leaching and the decomposition of hydrogen peroxide on the catalyst surface. Therefore, the initial pH of the solution affects the production of OH• radicals as a result of the decomposition of H_2O_2 (Lian et al., 2019).

As seen in Figure 7, the color removal of almost 95% was achieved after 90 min reaction time under an initial pH of 3.0, $CuFe_2O_4$ concentration of 1 g/L, H_2O_2 concentrations of 500 mM, temperture of 25°C for 100 ppm of RR 2 dye concentration at an ultrasonic frequency of 50 Hz and power of 500 W. Moreover, 78.75% of dye decolorization efficiency was obtained at a natural pH value of 4.0 without pH adjustment.

The pH value is generally optimized at 3.0 in Fenton and Fenton-like studies in many studies in the literature. In this study, the highest decolorization efficiency obtained at an initial pH of 3.0 can be explained by the increased formation of OH• radicals resulting from the dissolution of more iron in the acidic environment.

The decrease in decolorization efficiency at high pH values can be explained by the formation of fewer OH• radicals due to the dissociation of H_2O_2 into O_2 and H_2O or the formation of complexes such as iron (III) hydroxide. In addition, the increase in carbonate and bicarbonate anions can lead to a decrease in the effectiveness of mineralization because they act as scavengers for OH• radicals at higher pH values (Wang et al., 2016). Therefore optimum initial pH value was determined as 3.0 in this study.

The progression of the sono Fenton-like decolorization of RR 2 dye was monitored through UV-vis spectral analysis. The variations in the spectrum over time are presented in Figure 8.

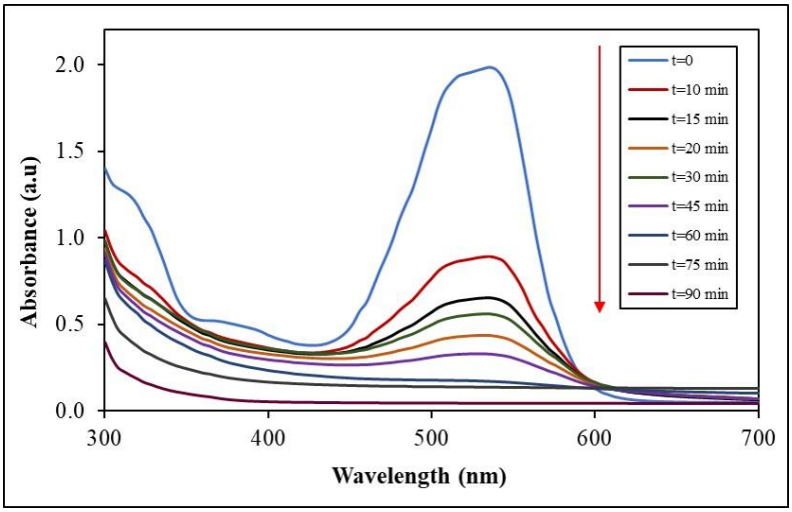

Figure 8. The UV-vis spectral analysis of RR 2 dye during the sono Fenton-like decolorization (C_0=100 mg/L $C_{H_2O_2}$ = 500 mM, X_0=1 g/L, pH=3.0, T= 298 K, US =50 Hz, 500 W)

RR 2 exhibits an absorption peak at 538.04 nm, which is attributed to the π→π* electronic transition within a conjugated system comprising azo groups (Zhu et al., 2015). As demonstrated in Figure 8, there was a progressive decline and eventual disappearance of the adsorption peaks as the reaction time increased. Additionally, no new peaks were identified that emerged during the reaction process. As a result, the chromophoric group (N=N group) and the conjugated system in the RR 2 molecular structure were broken, leading to the decolorization of the dye molecule.

The decolorization mechanism of this process is considered to be the combined effects of the ultrasound and $CuFe_2O_4$ catalyst on the decomposition of H_2O_2 into OH• radicals. The production cycles of OH• radicals by US- H_2O_2-$CuFe_2O_4$ system are shown in Equations (2) – (11) (J. H. Chu et al., 2020; Feng et al., 2016);

$$H_2O_2 + US \rightarrow 2HO\bullet \quad (2)$$
$$\equiv Fe^{3+} + H_2O_2 \rightarrow \equiv Fe^{2+} + H^+ + HO_2\bullet \quad (3)$$
$$\equiv Fe^{3+} + HO_2\bullet \rightarrow \equiv Fe^{2+} + H^+ + O_2 \quad (4)$$
$$\equiv Fe^{2+} + H_2O_2 \rightarrow \equiv Fe^{3+} + OH^- + OH\bullet \quad (5)$$

$$Cu^{2+} + H_2O_2 \rightarrow Cu^+ + O_2\bullet^- + 2H^+ \quad (6)$$
$$Cu^+ + H_2O_2 \rightarrow Cu^{2+} + OH^- + OH\bullet \quad (7)$$
$$Cu^+ + H_2O_2 \rightarrow Cu^{3+} + 2OH^- \quad (8)$$
$$\equiv Cu^{2+} + H_2O_2 \rightarrow \equiv Cu^+ + 2H^+ + O_2\bullet^- \quad (9)$$
$$\equiv Cu^{2+} + O_2\bullet^- \rightarrow \equiv Cu^+ + O_2 \quad (10)$$
$$\text{Organic dyes} + OH\bullet \rightarrow \text{Degraded products} \quad (11)$$

Initially, H_2O_2 molecules were decomposed by ultrasound irradiation in the presence of $CuFe_2O_4$, generating 2HO• (Eq. (2)). Concurrently, the Fenton reaction between $CuFe_2O_4$ and H_2O_2 was boosted by the ultrasound process. The $\equiv Fe^{3+}$ was first reduced to $\equiv Fe^{2+}$ by reaction with adsorbed H_2O_2 and HO_2• on the surface of the $CuFe_2O_4$ (Eqs. (3) and (4)). The $\equiv Fe^{2+}$ produced then reacted with the H_2O_2 in a mechanism analogous to the well-known Haber-Weiss process to generate OH• and $\equiv Fe^{3+}$ (Eq. (5)) (J. H. Chu et al., 2020; Feng et al., 2016).

It is widely accepted that the initial reduction of Cu^{2+} to Cu^+ occurs during its reaction with H_2O_2 (Eq. (6)). Subsequently, the Cu^+ produced is hypothesized to react with H_2O_2, resulting in the formation of OH• (Eq. (7)) or Cu^{3+} (Eq. (8)). Nevertheless, the process remains

opaque and necessitates additional study. The activation of H_2O_2 by CuO has been reported by Feng et al. (2016). The proposed mechanism was that $\equiv Cu^{2+}$ could be reduced to $\equiv Cu^{+}$ by H_2O_2 (Eq. (9)) and $O_2^{\bullet-}$ (Eq. (10)). Consequently, the circulation of $\equiv Cu^{2+}/\equiv Cu^{+}$ likely to be implicated in the activation of H_2O_2 by $\equiv Cu^{2+}$ on the surface of $CuFe_2O_4$ particles (J. H. Chu et al., 2020; Feng et al., 2016). Finally, the OH• produced in the earlier reactions degraded the organic dyestuffs (Eq. 11).

CONCLUSIONS

In this study, magnetic spinel $CuFe_2O_4$ particles were prepared via the green synthesis method utilizing the ethanolic extract of pomegranate peel. The characterization studies confirmed that $CuFe_2O_4$ particles were successfully synthesized. The catalytic property of $CuFe_2O_4$ particles was investigated in the removal of Reactive Red 2 anionic azo dye by a heterogeneous sono Fenton-like process. In the sono catalytic experiments, ≈ 95% of color removal was obtained for 100 mg/L of RR 2. UV-vis spectral analysis revealed the cleavage of the azo band in the chromophore of the dye by OH• radicals.

Consequently, a novel catalyst material can be synthesized by efficiently evaluating food waste, such as pomegranate peels. Furthermore, these magnetic spinel copper ferrite particles derived from bio-waste have the potential to be used in various applications, including wastewater treatment, as outlined in this study.

ACKNOWLEDGMENTS

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STOCHASTIC PERTURBED (2+1)-DIMENSIONAL BISWAS-ARSHED EQUATION AND STOCHASTIC OPTICAL SOLITON SOLUTIONS UNDER THE EFFECT OF WHITE NOISE

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ABSTRACT
In this study, optical soliton solutions of the stochastic form of the (2+1)-dimensional perturbed Biswas-Arshed equation are examined. The Biswas-Arshed model is one of the important nonlinear equations modeling soliton conduction in the absence of self-phase modulation and is still the subject of many studies in this context. By applying a complex wave transformation containing the Wiener process term to the examined model, the model is transformed into a nonlinear ordinary differential equation form, and an analytical method applicable form is obtained. By separating the obtained form into real and imaginary parts, the nonlinear ordinary differential equation, which is the source of constraint equations and the analytical method, is obtained. In the next stage, by applying the new Kudryashov method, bright and dark soliton solutions are gained in a noise-free state. In the next stage, noise effect analysis is carried out on bright and dark soliton forms by giving different values to the noise strength parameter in order to observe the noise effect. The findings obtained are interpreted in detail in the relevant parts of the article, supported by 3D and 2D figures.
Keywords: (2+1)-dimensional perturbed Biswas-Arshed equation; Wiener process; Stochastic optical soliton solutions; Noise strength; The new Kudryashov method.

1. Introduction

Human beings have always been curious and eager to learn, not only about the planet they live in, but also about understanding events related to the universe. At this point, there is no doubt that not only differential equations but also nonlinear partial differential equations (NLPDE) gain great importance. Because differential equations are inadequate when it comes to modeling many problems in nature mathematically. However, it is not possible to say that much progress was made, especially in obtaining real solutions of NLPDEs, until the last quarter of the last century. In this context, the first quarter of this century constitutes the golden age in terms of the design and solution of different NLPDE models. On the basis of this, fiber optic-based research developed in connection with solid state physics in the 1970s [1,2], developments in computer technology, huge developments in the field of communication and internet, advances in the field of computer software for these areas and the needs of technical developments in this field (memory, processor, disk, graphics processors, storage units, etc.) can be given as major factors. Undoubtedly, an important factor that can be considered among these is the development of symbolic calculation programs and the fact that such utilities take up a lot of time in the work of researchers working in this field and have probably made some mathematical operations easier. Nonlinear optics is a fundamental field that has been studied especially since the 1970s. Although this field has a unique field and importance, especially with the discovery of fiber optics, today it is an area that is in the focus of many researchers not only in intercontinental data transfer and communication but also in terms of interplanetary communication. Basically, many models have been developed and continue to be developed, focusing on modeling data transmission in optical fibers. Among these models that form the basis for nonlinear optics, the Schrödinger-Hirota equation [3], the Sasa-Satsuma model [4], the Lakshmanan-Porsezian-Daniel (LPD) equation [5], the Radhakrishnan-Kundu-Lakshmanan (RKL) equation [6], the Biswas-Milovic equation [7], the Chen-Lee-Liu equation [8], the Fokas-Lenells equation [9], the Gerdjikov-Ivanov equation [10], the Eckhaus equation [11] can be given as examples. However, it should be emphasized that the models in this field are not limited to those given as examples and listed above. It is possible to find dozens of other models in the literature, where both these models are the point of inspiration and focus on such models. One of the models in this field is the (1+1) dimensional perturbed Biswas-Arshed model, which has been recently introduced in the literature [12].

The perturbed (1+1)-dimensional Biswas-Arshed equation, which models optical soliton transmission based on the interaction between perturbation and nonlinear dispersion in the absence of the self-phase modulation is given as [12]:

$$iu_t + a_1 u_{xx} + a_2 u_{xt} + i\left(b_1 u_{xxx} + b_2 u_{xxt}\right) = i\left(\rho\left(|u|^2 u\right)_x + \sigma\left(|u|^2\right)_x u + \theta|u|^2 u_x\right), \qquad (1)$$

where $u = u(x,t)$ is the complex function related to spatial x and temporal t. iu_t represents temporal evolution, $a_1 u_{xx}$ represents group velocity dispersion (or namely chromatic dispersion GVD/CD), $a_2 u_{xt}$ stands for spatio-temporal dispersion (STD), $ib_1 u_{xxx}$ comes to mean the third-order dispersion (TOD), $ib_2 u_{xxt}$ is the spatio-temporal third-order dispersion. On the right side of the Eq.(1), $i\rho\left(|u|^2 u\right)_x$ is self-steepening (SS), $i\sigma\left(|u|^2\right)_x u$ is self-frequency shift (SFS), and the $i\theta|u|^2 u_x$ is nonlinear dispersion (ND) term. In Eq.(1), all of the coefficients are non-zero real numbers. Additionally, the right side of the equation represents perturbation. Many researchers have different studies in the literature regarding the model given in Eq.(1) [13-19]. This study presents the (2+1)-dimensional expansion of the model given in Eq.(1) with a stochastic term in the form below:

$$iu_t+\lambda_1\left(u_{xx}+u_{yy}\right)+\lambda_2\left(u_{xt}+u_{yt}\right)+i\left(\tau_1 u_{xxx}+\tau_2 u_{xxt}\right)$$
$$=i\left(\alpha\left(|u|^2u\right)_x+\beta\left(|u|^2\right)_x u+\mu|u|^2u_x\right)+\sigma\left(u-i\lambda_2\left(u_x+u_y\right)\right)W_t(t), \quad (2)$$

where u=u(x,y,t) is the complex function, $\lambda_1,\lambda_2,\tau_1,\tau_2,\alpha,\beta,\mu,\sigma$ are the real coefficients of the GVD, STD, TOD, spatio-temporal TOD, SS, SFS, ND, noise strength, respectively. W(t) represent the standard Wiener process.

Although the noise effect is a concept that emerged in connection with statistical studies and stochastics, it is of great importance in terms of engineering problems. In this context, during the design of engineering structures, it is an element that is taken into consideration by the engineers and researchers who make the design, both in terms of the safety of the structures and the effects they will be exposed to. From this perspective, it is a concept that is the subject of research not only in terms of models based on statistics, but also in many areas of life (medicine, genetics, ocean science, aeronautical engineering, aviation, nonlinear optics, quantum, bioengineering etc.). There have been significant studies in recent years regarding the stochastic forms of NLPDEs, and these studies point to the topicality and importance of the subject [20-26].

The structure of the article is presented as follows: Section (II) presents the mathematical analysis. Section (III) captures the new Kudryashov method's (nKM) algorithm. Section (IV) stands for utilization of the nKM and gaining the stochastic optical soliton solutions of Eq.(2). Section (V) captures the graphical simulations. Lastly, Section (VI) covers the Conclusion.

2. Mathematical analysis of Eq.(2) by utilizing the wave transformation

In order to get the nonlinear ordinary differential equation form of Eq.(2), let's assume the transformation as follows:

$$u(x,y,t)=U(\xi)\exp(i\Omega(x,y,t)), \qquad \Omega(x,y,t)=k(x+y)+\omega t+\sigma(W(t)-\sigma t)+\varphi_0,\ \xi=px+qy-vt, \quad (3)$$

where $U(\xi)$ is the real valued amplitude function, ξ represents the new variable after transformation, $\Omega(x,y,t)$ stems from phase component, ω,k,v represent the frequency, wave number, velocity, respectively. φ_0 flags the phase constant. Inserting Eq.(3) into Eq.(2), one can derive the following result, which comes from the imaginary part:

$$3p^2(p\tau_1-\tau_2 v)U''+6\sigma(p\lambda_2+q\lambda_2-kp\tau_2)U\frac{dW(t)}{dt}-(3\alpha p+2\beta p+\mu p)U^3$$
$$+3\begin{pmatrix}\left(\sigma^2-\omega\right)\left(2\tau_2 kp-\lambda_2(p+q)\right)-v\left(1+2k\lambda_2\right)\\-k^2\left(3\tau_1 p+\tau_2 v\right)+2\lambda_1 kp(p+q)\end{pmatrix}U=0, \quad (4)$$

where $U=U(\xi)$. Since $U,U'',W'\neq 0$, Eq.(4) has the following constraints:

$$\lambda_2=\frac{kp\tau_2}{p+q}, \quad (5)$$

$$\mu=-3\alpha-2\beta, \quad (6)$$

$$v=\frac{p\tau_1}{\tau_2}, \quad (7)$$

$$\omega=\frac{\left(k\sigma^2\tau_2^2+2k\left(\lambda_1-2k\tau_1\right)\tau_2-\tau_1\right)p^2+pq\left(k\sigma^2\tau_2^2-2k\left(k\tau_1-2\lambda_1\right)\tau_2-\tau_1\right)+2\lambda_1 kq^2\tau_2}{pk\tau_2^2(p+q)}. \quad (8)$$

Inserting Eq.(3) into Eq.(2), one can gain the following result, which comes from the real :

$$\left(p^2\sigma\tau_2\left(\sigma-W'(t)\right)-3kp^2\tau_1+p\tau_2\left(2kv-\omega p\right)+\lambda_1\left(p^2+q^2\right)-v\lambda_2\left(p+q\right)\right)U''+k\left(\alpha+\mu\right)U^3$$
$$+\sigma\left(k^2\tau_2-4k\lambda_2-2\right)UW'(t)+\left(\tau_1k^3-\left(\tau_2k^2-2k\lambda_2-1\right)\left(\sigma^2-\omega\right)-2\lambda_1k^2\right)U=0. \quad (9)$$

In the Eq.(9), since the W(t) represents a first-order function dependent on t, Eq.(9) is called the NODE form of Eq.(2) and utilization of the homogeneous balance principle between the terms U'',U^3, results N=1, which is the balancing constant.

3. The new Kudryashov method (nKM) [26, 27]

We consider that Eq.(9) has the following solution form:

$$U\left(\xi\right)=A_0+\sum_{i=1}^{N}A_iR^i\left(\xi\right)=0. \quad (10)$$

Here A_i stand for real numbers such that $A_N\neq 0$ and $R\left(\xi\right)$ comes from the following formula:

$$\left(\mathrm{R}'(\xi)\right)^2=\delta^2\mathrm{R}^2\left(\xi\right)\left(1-\eta\mathrm{R}^2\left(\xi\right)\right). \quad (11)$$

Equation (11) accepts the fallowing solution:

$$R\left(\xi\right)=\frac{4L}{4L^2e^{\delta\xi}+\eta e^{-\delta\xi}}, \quad (12)$$

where η,δ,L are real numbers.

Equation (12) also has the following hyperbolic form:

$$R(\xi)=\frac{4L}{\left(4L^2+\eta\right)cosh\left(\delta\xi\right)+\left(4L^2-\eta\right)sinh\left(\delta\xi\right)}, \quad (13)$$

Which leads to bright soliton when $\eta=+4L^2$,

$$R(\xi)=\frac{1}{2L}sech\left(\delta\xi\right). \quad (14)$$

and serves to singular solution when $\eta=-4L^2$,

$$R(\xi)=\frac{1}{2L}csch\left(\delta\xi\right). \quad (15)$$

4. Utilization of the nKM and gathering the optical soliton solution

Remembering that the balancing constant is N=1, Eq.(10) takes the following formula:

$$U\left(\xi\right)=A_0+A_1R\left(\xi\right). \quad (16)$$

Mounting the Eqs. (16), (11) along with Eqs.(5-8) into Eq.(4), the following system is derived:

$$R^0(\xi): A_0\left(k^3\tau_1+\left(-\frac{1}{2}\sigma^2\tau_2+\omega\tau_2-2\lambda_1\right)k^2+\left(\left(\mu+\alpha\right)A_0^2-2\lambda_2\omega\right)k-\omega\right)=0,$$

$$R^1(\xi): \left(\left(-\frac{\sigma^2}{2}+\omega\right)\tau_2-2\lambda_1\right)k^2+\left(p\delta^2\left(2v\tau_2-3p\tau_1\right)-2\lambda_2\omega+3\left(\mu+\alpha\right)A_0^2\right)k$$

$$+k^3\tau_1+\left(\left(\left(\frac{\sigma^2}{2}-\omega\right)\tau_2+\lambda_1\right)p^2-\lambda_2 pv+q\left(q\lambda_1-v\lambda_2\right)\right)\delta^2-\omega=0, \quad (17)$$

$$R^2(\xi): A_0\left(\mu+\alpha\right)=0,$$

$$R^3(\xi): \left(\left(6k\tau_1+\left(2\omega-\sigma^2\right)\tau_2-2\lambda_1\right)p^2-2v\left(2k\tau_2-\lambda_2\right)p-2q\left(q\lambda_1-v\lambda_2\right)\right)\eta\delta^2+kA_1^2\left(\mu+\alpha\right)=0,$$

where λ_2,μ,v,ω are flagged as in Eqs.(5-8).

By the virtue of any symbolic calculation software, Eq.(17) generates the following solution sets:

$$Set_{1,2}=\left\{\begin{array}{l}\alpha=-\beta,p=\mp\left(\sqrt{2}\pm1\right)q,A_0=1,A_1=A_1,\tau_1=\dfrac{k\sigma^2\tau_2^2\sqrt{2}}{4k^2\tau_2\left(\sqrt{2}\pm1\right)+2\sqrt{2}},\\ \delta=1,\lambda_1=-\dfrac{\sigma^2\tau_2\left(k^4\tau_2^2\left(5\sqrt{2}\pm7\right)+2k^2\tau_2\left(2\sqrt{2}\pm3\right)+\sqrt{2}\pm1\right)}{\left(4k^2\tau_2\left(7k^2\tau_2+4\right)+4\right)\sqrt{2}\pm20k^2\tau_2\left(2k^2\tau_2+1\right)}\end{array}\right\}. \quad (18)$$

Combination of the Eq.(16) with the Eqs.(3), (5), (6), (7), (8), (12), produces:

$$u(x,y,t)=\left(A_0+\frac{4A_1L}{4L^2e^{\delta\left(px+qy-\frac{p\tau_1t}{\tau_2}\right)}+\eta e^{-\delta\left(px+qy-\frac{p\tau_1t}{\tau_2}\right)}}\right)e^{i\left(k(x+y)+\omega t-\frac{\sigma^2t}{2}+\phi_0\right)}. \quad (19)$$

Equation (19) also can be arranged in the following form:

$$u(x,y,t)=\left(A_0+\frac{4A_1L}{\left(4L^2+\eta\right)\cosh\left(\delta\left(px+qy-\frac{p\tau_1t}{\tau_2}\right)\right)+\left(4L^2-\eta\right)\sinh\left(\delta\left(px+qy-\frac{p\tau_1t}{\tau_2}\right)\right)}\right)e^{i\left(k(x+y)+\omega t-\frac{\sigma^2t}{2}+\phi_0\right)}, \quad (20)$$

which falls into the bright soliton when $\eta=+4L^2$,

$$u(x,y,t)=\left(A_0+\frac{A_1}{2L}\operatorname{sech}\left(\delta\left(px+qy-\frac{p\tau_1t}{\tau_2}\right)\right)\right)e^{i\left(k(x+y)+\omega t-\frac{\sigma^2t}{2}+\phi_0\right)}, \quad (21)$$

and singular solution when $\eta=-4L^2$,

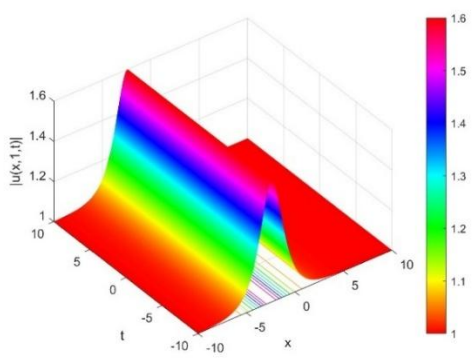
$$u(x,y,t)=\left(A_0+\frac{A_1}{2L}\operatorname{csch}\left(\delta\left(px+qy-\frac{p\tau_1t}{\tau_2}\right)\right)\right)e^{i\left(k(x+y)+\omega t-\frac{\sigma^2t}{2}+\phi_0\right)}. \quad (22)$$

where $A_0,\delta,\alpha,\lambda_1,\tau_1,p$ are presented in Eq.(18) and λ_2,μ,v,ω are given with Eqs.(5-8).

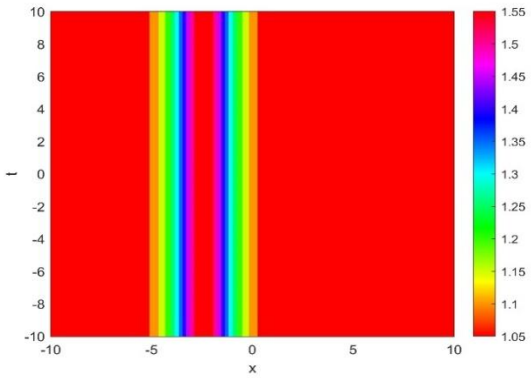
5. Simulations of the obtained solutions

In this section, it is aimed to examine the ability of Eq.(2) to produce dark and bright solitons, as well as the noise effect on these soliton forms, by presenting the obtained stochastic optical soliton solutions graphically. The graphical presentation of the form obtained by the Set1 combination of the solution function presented in Eq.(19) with Set_1 in Eq.(18) and the parameter selection as $\{\sigma=0.001, L=1, \eta=4, A_1=1.2, k=0.65, q=2.25, \tau_2=0.6, \varphi_0=0.5, y=1\}$ is

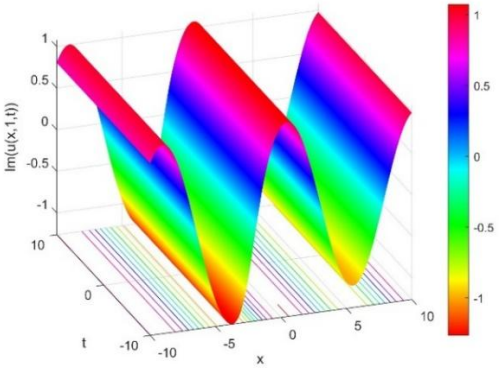
visualized with Fig.1. Figure represents the bright soliton. The same methodology is used this time in Fig.2. The only difference in Fig.2 is that A_1=-1.2 is selected. As can be clearly seen, the form represented by Fig.2 is a dark soliton, and this form is a form that cannot be observed on the oscilloscope screen under normal conditions, but can be seen when there is a dark background. Another point that should be emphasized here is that with Fig.1 and Fig.2, it is primarily aimed to obtain bright and dark soliton forms in the absence of noise effect. With Figs.3,4, it is aimed to make a comparison by examining under the influence of noise effect. However, in the parameter selections made for both Fig.1 and Fig.2, the noise effect is preferred as $\sigma = 0.001$, as it cannot be overlooked. The main reason for this is that, as can be seen from the explicit form of the solution represented by Eq.(19), the term "τ_1" is a multiplier of temporal "t". In the $Set_{1,2}$ given in Eq.(18) , "τ_1" depends on "σ" and choosing $\sigma = 0.0001$ will prevent the solution from becoming a time-dependent form, which will eliminate its dependence on temporal "t". Therefore, the selection of $\sigma = 0.001$ is chosen in a sense to eliminate this negativity, but also as a value close to zero. The basis for presenting the Figs.3,4 is the noise effect analysis on bright and dark soliton forms. In this context, Fig.3 is presented as the bright soliton form presented in Fig.1, and Fig.4 is presented as the noise effect effects on the dark soliton form presented in Fig.2. As can be clearly seen from both Fig.3 and Fig.4 presentations, a significant fluctuation effect is observed on the respective soliton forms due to increasing σ values.



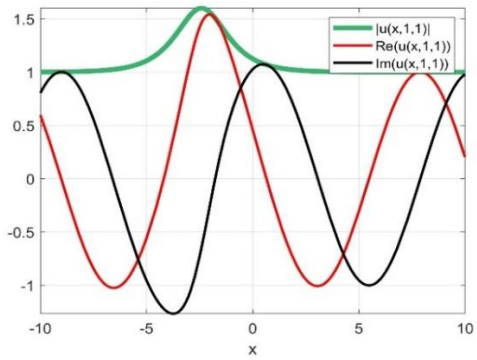
(a) $|u(x,y,t)|$ in 3D



(b) Contour of $|u(x,y,t)|$

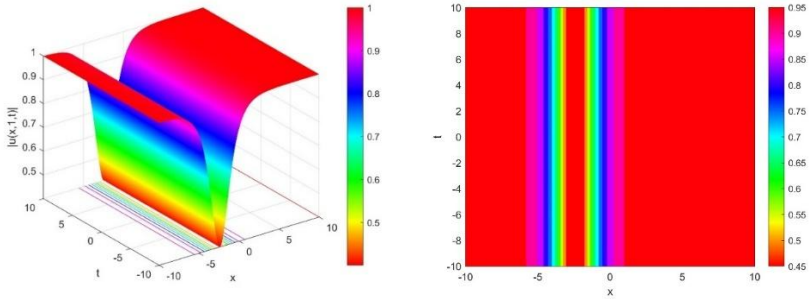


(c) $Im(u(x,y,t))$

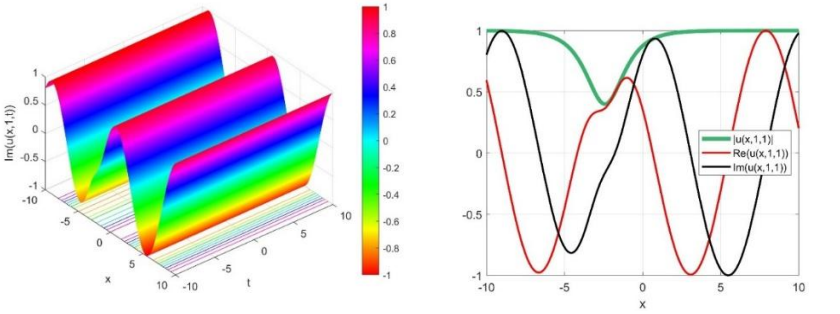


(d) $|u(x,1,t)|, Re(u(x,1,1)), Re(u(x,1,1))$

Figure 1. Bright soliton depiction of Eq.(19) with the aid of Set_1 in Eq.(18) and selected parameters as $\{$sigma=0.001, L=1, η=4, A_1=1.2, k=0.65, q=2.25, τ_2=0.6, φ_0=0.5, y=1$\}$.

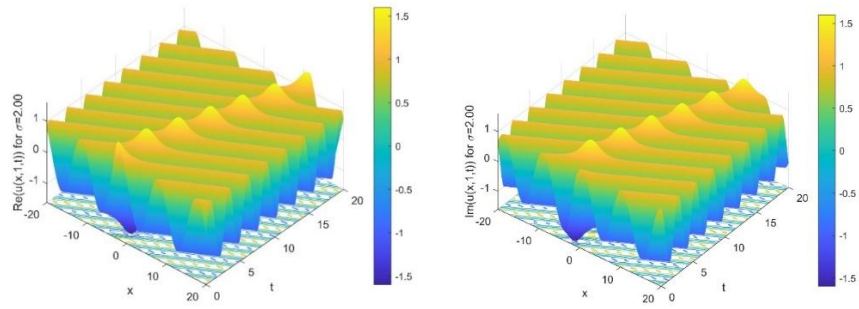


(a) $|u(x,y,t)|$ in 3D (b) Contour of $|u(x,y,t)|$

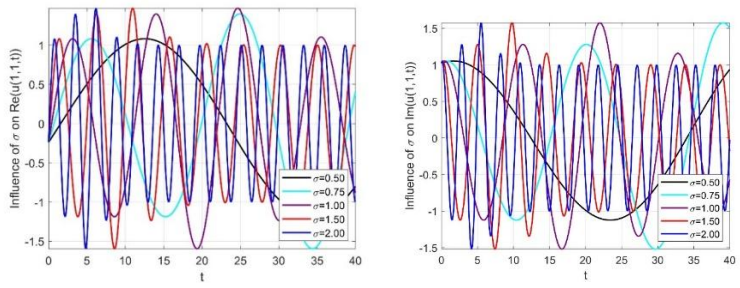


(c) $Im(u(x,y,t))$ (d) $|u(x,1,t)|, Re(u(x,1,1)), Re(u(x,1,1))$

Figure 2. Dark soliton view of Eq.(19) with the aid of Set_1 in Eq.(18) and selected parameters as $\{\sigma=0.001, L=1, \eta=4, A_1=-1.2, k=0.65, q=2.25, \tau_2=0.6, \varphi_0=0.5, y=1\}$.

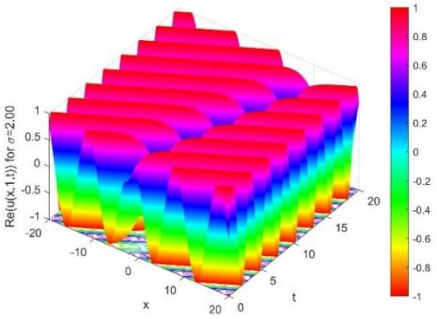


(a) $Re(u(x,y,t))$ in 3D for $\sigma=2$ (b) $Im(u(x,y,t))$ in 3D for $\sigma=2$

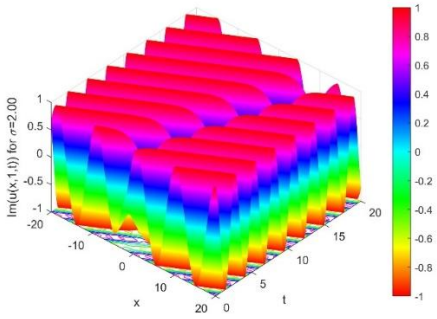


(c) Effect of on $Re(u(1,1,t))$ (d) Effect of on $Im(u(1,1,t))$

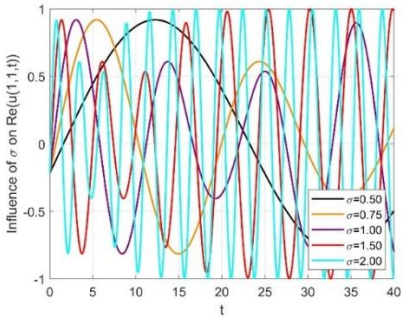
Figure 3. Effect of noise on bright soliton in figure 1.



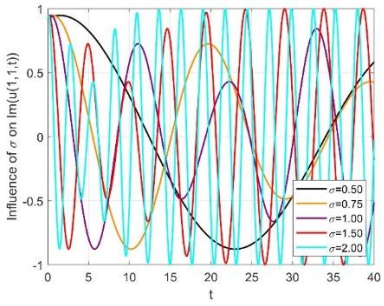
(a) $Re(u(x,y,t))$ in 3D for $\sigma = 2$



(b) $Im(u(x,y,t))$ in 3D for $\sigma = 2$



(c) Effect of on $Re(u(1,1,t))$



(d) Effect of on $Im(u(1,1,t))$

Figure 4. Effect of noise on dark soliton in figure 2.

6. Conclusion

In this study, a stochastic form was designed for the form of the (2+1)-dimensional expansion of the (1+1)-dimensional perturbed Biswas-Arshed equation, and the aim of examining the noise effect on these forms with the ability of this form to produce bright and dark optical solitons was successfully achieved. has been completed. For this, stochastic optical soliton solutions were obtained with the new Kudryashov method, and 3D and 2D graphical presentations of these solutions were made with appropriate solution algorithms, set acquisition and parameter selections. The findings obtained show that the (2+1)-dimensional perturbed Biswas-Arshed equation can produce bright and dark soliton forms, and the studies on the stochastic form show that the noise effect causes a significant fluctuation. It may be possible that both this form and its different versions may be of interest to researchers working in this field.

Declaration of the conflict of interest

All authors of the article undertake that there is no conflict of interest.

Data availability statements

Since all the methods and data used in solving the problem are presented in the article, data sharing is not applicable for the manuscript.

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COMPARISON OF DIFFERENT MAIZE VARIETIES FOR SILAGE NUTRITIONAL PROPERTIES

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Abstract
The study compares the feed quality characteristics of different silage maize cultivars. Four different maize cultivars (Everest, Hido, DKC-6442, P32W86) were used. The differences between the varieties were statistically significant in many of the examined characteristics. According to the research results, pH values varied between 3.66 and 3.89, Crude protein content between 8.46 and 10.35%, Crude fiber content between 17.89 and 21.08%, Crude ash content between 3.72 and 4.90%, neutral detergent fiber (NDF) values between 37.53 and 40.85%, acid detergent fiber (ADF) values between 21.09 and 25.06% and acid detergent lignin (ADL) content between 2.74 and 3.15%. Dry matter digestibility (DMD) varied between 69.38 and 72.47%, dry matter intake (DMI) ranged between 2.95 and 3.21%, and Relative feed value (RFV) varied between 158.44 and 179.57. In conclusion, the study highlights significant differences in the nutritional properties of silage made from different maize cultivars. Hido and DKC-6442 generally showed better nutritional values regarding DDM, DMI, and RFV, while P32W86 had lower values in these categories. These findings can help select the most suitable maize cultivar based on specific nutritional requirements for silage production.
Keywords: maize, silage, fiber, relative feed value

Introduction

Maize silage is a crucial feed source in livestock production, offering a balance of energy and fiber that supports animal health and productivity. The process of ensiling maize preserves nutrients through anaerobic fermentation, resulting in a palatable and digestible feed. Compared to other silage crops, maize silage typically yields higher energy content and digestibility, making it a preferred choice for many farmers (Kaplan et al., 2016).

The economic advantages of using maize silage in livestock operations are significant. It provides a cost-effective way to store large quantities of high-quality feed, reducing reliance on purchased concentrates. Additionally, maize silage production can be mechanized, lowering labor costs and increasing efficiency. The economic advantages of using maize silage in livestock operations are significant. It provides a cost-effective way to store large quantities of high-quality feed, reducing reliance on purchased concentrates. Additionally, maize silage production can be mechanized, lowering labor costs and increasing efficiency (Kamalak et al., 2003; Kokten, 2020). In addition to environmental factors such as soil type, climate, and water availability, variety differences greatly affect maize silage production. Farmers must consider these factors when planning their silage program to ensure optimal yields and quality.

In plant production, variety differences have important effects on yield and feed characteristics (Assefa and Ledin, 2001). Plant varieties with different genetic structures may differ in features such as growth rate, biomass production, nutrient content, and digestibility. Especially in forage plants, variety selection is decisive in parameters that directly affect feed quality, such as crude protein ratio, cellulose, and lignin content of the obtained product (Beever and Mould, 2000) These differences observed between different varieties grown in the same environmental conditions reveal that appropriate variety selection is critical in terms of increasing productivity in animal husbandry (Kingston-Smith et al., 2013). Therefore, studies aiming to improve yield and feed quality should be carried out by taking into account the morphological and biochemical characteristics of the varieties.

New maize varieties are improved in our country every season. Testing these new improved varieties in terms of yield and quality characteristics in different climate and soil conditions is of great importance for agriculture and animal husbandry (Harmanlıoglu, 2019). The aim of this study is to determine the superior variety or varieties in terms of silage quality of some maize cultivars that are widely cultivated.

Materials and Methods

The research was conducted on a farmer's land in Çöteli Village, a district of Elazığ province, during the 2022 growing season. A total of four registered silage maize cultivars were used as material in the study: “P32W86” supplied by Pioneer Seeds, “DKC-6442” supplied by Monsanto Food and Agriculture, and “Hido” and “Everest” supplied by May-Agro Seeds. The continental climate prevails in Elazığ province, where the research was conducted; winters are cold and rainy, and summers are hot and dry. According to the data of Elazığ Meteorology Regional Directorate, the temperature, precipitation, and relative humidity averages for 2022, when the trial was conducted, and long-term averages are presented in Table 1.

Table 1. Some climate data for Elazığ province covering long years (1939-2021) and the vegetation period of the research year

Months	**Temperature (°C)**		**Precipitation (mm)**		**Relative Humidity (%)**	
	2022	**Long Term**	**2022**	**Long Term**	**2022**	**Long Term**
July	27.1	28.0	0.0	0.96	30.7	28.4
August	29.7	28.2	0.1	2.63	26.6	27.8
September	23.7	23.8	4.1	6.06	30.6	31.4
October	15.6	16.8	20.0	19.67	52.3	48.8
Mean/Total	**24**	**24.2**	**24.2**	**29.3**	**35**	**34.1**

During the period when the study was conducted, the average temperature was recorded as 24 °C, the total rainfall was 24.2 mm, and the average relative humidity was 35%. It is seen that these data are close to the long-term averages (Table 1).

When the textural structure of the soil of the experimental field is examined, it falls into the loamy texture class. The pH level of the soil is slightly alkaline, with 7.78. It is moderate in terms of lime (10.64%), insufficient in organic matter (0.42%), and rich in available phosphorus (21.36 kg/da P_2O_5) (Aydın and Sezen, 1995).

The research was carried out in the 2nd crop conditions according to the randomized block experimental design with three replications. The 4 maize cultivars considered were planted in a total of 12 plots. The row spacing was adjusted to 70 cm, and the row spacing was 15 cm. Planting was done manually on July 7, 2022, in the previously prepared and adjusted seed bed. Along with planting, 35 kg DAP base fertilizer was applied to all plots, providing 6.3 kg nitrogen and 16.1 kg phosphorus per decare. After planting, a sprinkler irrigation system was established in the trial area to ensure seed germination. Irrigation times were determined according to phenological observations, and each irrigation process was carried out for an average of 3 hours. Weed control was carried out manually until the plants reached the 3-5 leaf stage, and after this period, hand hoeing was used. The final hoeing process was carried out when the plants reached 50-60 cm in length, and the throat filling process was carried out at this stage. After the throat filling process, a drip irrigation system was established so that a line would come between every two rows, and irrigation times were determined according to phenological observations until the harvest period. Each irrigation was carried out with the drip irrigation system under 2 bar pressure and for an average of 6 hours. In addition, 15 kg of Urea fertilizer was applied through the drip irrigation system, providing 6.9 kg of pure nitrogen per decare. Top fertilizer was applied with drip irrigation, 20 kg of Urea fertilizer was applied so that 9.2 kg of pure nitrogen would come per decare. The plants were harvested on October 22, 90-100 days after the seed emergence date, during the dough development period. The harvest was carried out in the middle of the 2 rows of the plots, consisting of 4 rows in each plot, representing the plot. Within the scope of these observations, plant height, the part of the plant from the soil surface to the top point, was measured in cm, and the average of the measurement results was taken. All plants were cut into pieces of approximately 2.5-3 cm length and filled into 2 kg vacuum bags; the air was removed, and the mouth was closed. The samples were stored in a dark place (24±2°C) for 60 days. 30 g of sample taken from the opened silages was mixed with 270 ml of water, and the pH was measured. The silage samples were dried in a drying cabinet at 70°C (until they reached constant weight). Samples were prepared by grinding in a mill with a 1 mm sieve diameter for analysis.

The crude ash content of the silage samples was determined by burning them in a muffle furnace at 550 °C for 8 hours (AOAC, 1990). The Kjeldahl method was used to determine the nitrogen (N) content of the silages. The crude protein ratio was calculated with the Nx6.25 formula (AOAC, 1990). Crude fiber, ADF, ADL, and NDF were done using the ANKOM Tech methods (2017). With the help of ADF and NDF, SKM (digestible dry matter), DMT (dry matter consumption), and NYD (relative feed value) were calculated (Morrison, 2003).

Statistical analysis

The findings obtained as a result of the research were subjected to variance analysis according to the randomized block experimental design using the SAS (SAS Inst., 1999) package program. The LSD test was used to determine whether the difference between the means was significant.

Result and Discussion

The results of some biochemical analyses of the silage of maize varieties are given in Table 2. The effect of variety was significant ($p \leq 0.01$) except for crude fiber and NDF. pH

value was highest in the Hido variety (3.89) and lowest in the P32W86 variety (3.66). Crude protein content was highest in the Everest variety (10.35%) and lowest in the DKC-6442 variety (8.46%). There was no statistically significant difference between the crude fiber ratios; the highest value was found in the P32W86 variety at 21.08%, and the lowest was found in the DKC-6442 variety, with 17.89%. Crude ash content was highest in the Hido variety (4.90%) and lowest in the DKC-6442 variety (3.72%).

While there was no significant difference between the varieties regarding NDF (Neutral Detergent Fibre) content, the highest value was found in the Everest variety at 41.24% and the lowest in the Hido variety at 37.53%. The highest ADF (Acid Detergent Fibre) content was found in the P32W86 variety (25.06%) and the lowest in the DKC-6442 variety (21.09%). The highest ADL (Acid Detergent Lignin) content was found in the P32W86 variety at 3.15% and the lowest in the Hido variety at 2.74%. These results revealed that silage maize varieties differed regarding crude protein, ADF, and ADL contents.

Table 2. Some biochemical properties of maize cultivars' silage

Cultivars	pH	Crude Protein (%)	Crude Fiber (%)	Crude Ash (%)	NDF (%)	ADF (%)	ADL (%)
Everest	3.72^{b}	10.35^{a}	19.00	4.18^{ab}	41.24	21.89^{ab}	2.85^{ab}
Hido	3.89^{a}	9.45^{b}	19.02	4.90^{a}	37.53	21.34^{b}	2.74^{b}
DKC-6442	3.71^{b}	8.46^{c}	17.89	3.72^{b}	39.22	21.09^{b}	2.98^{ab}
P32W86	3.66^{b}	9.51^{ab}	21.08	4.22^{ab}	40.85	25.06^{a}	3.15^{a}
Sg Dg	**	**	NS	**	NS	**	**
LSD	0.13	0.72	3.39	0.91	8.12	3.64	0.38

****:** p≤0.01; **Sg Dg:** Significant degree; **LSD:** least significant difference; **NS:** non-significant

Dry matter digestibility, dry matter intake, and relative feed value values of maize silage are given in Table 3. While the effect of variety on dry matter digestibility was found significant (p≤0.01), its impact on dry matter intake and relative feed value was found insignificant (p≥0.05). The highest DMD value was found in DKC-6442 with 72.47%, followed by Hido with 72.27% and Everest with 71.85%. The lowest DMD value was found in the P32W86 variety, which was 69.38%. There was no statistically significant difference between the varieties regarding dry matter intake (DMI) and relative feed value (RFV). DMI values ranged between 2.95 and 3.21%, while RFV values were highest in the Hido variety (179.57) and lowest in the P32W86 variety (158.44).

Table 3. Dry matter digestibility, dry matter intake, and relative feed value of maize cultivars' silage

Cultivars	DMD (%)	DMI (%)	RFV
Everest	71.85^{ab}	2.96	165.55
Hido	72.27^{a}	3.21	179.57
DKC-6442	72.47^{a}	3.08	173.51
P32W86	69.38^{b}	2.95	158.44
Sg Dg	**	NS	NS
LSD	2.84	0.63	41.05

DDM: dry matter digestibility; **DMI:** dry matter intake; **RFV:** relative feed value; ****:** p≤0.01; **Sg Dg:** Significant degree; **LSD:** least significant difference; **NS:** non-significant

Ball et al. (2001) indicated that dry matter and protein ratios of plants might differ based on plant genetic structure, leaf, ear and stem ratios, ripening periods, temperature and fertilization. Yilmaz et al. (2020), in their study conducted on 10 different maize cultivars,

stated that crude protein rates varied between 5.01% and 9.48%, and the highest value was obtained in the 72 MAY 80 cultivar. This result supports the Everest variety, which showed a similarly high protein content in our study. It was also emphasized that NDF and ADF values vary according to varieties and that this is directly related to silage digestibility. This reinforces the decisive effect of the variety differences observed in our study on nutritional values. Forage crops with reduced ADF and NDF levels are generally preferred, as high levels of these fibers can hinder digestibility and lower overall feed quality (Kaplan et al., 2014). In this study, the ADF and NDF values observed in the silage samples were in alignment with those reported in previous literature (Güney et al., 2010; Kavut et al., 2012; Yozgatlı et al., 2019; Çarpıcı and Öztürk, 2019).

Conclusion

This study compared different silage maize varieties' biochemical properties, digestibility, and feed value. According to the results of biochemical analyses, the highest crude protein content was found in the Everest variety, while the highest crude ash content was found in the Hido variety. Regarding fiber fractions, the P32W86 variety had the highest ADF and ADL content. According to the digestibility data, the highest dry matter digestibility was determined in DKC-6442 and Hido varieties. Regarding relative feed value, the highest value was determined in Hido, and the lowest value was determined in the P32W86 variety.

As a result of these findings, it can be said that certain varieties stand out to improve silage quality. Especially Everest variety may be more suitable for growers who desire high protein content, and DKC-6442 and Hido varieties may be more suitable for those who want to produce silage with high digestibility. Since the digestibility of the P32W86 variety, which has higher fiber content, is low, it may be recommended to use this variety in silage rations by mixing it with other varieties. Considering the nutrient content and digestibility, silage maize varieties suitable for regional growing conditions should be selected.

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DETERMINATION OF NUTRITIONAL PROPERTIES OF PLANT PARTS IN MAIZE CULTIVARS

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Abstract
This study was carried out to determine the nutritional values of plant parts (leaves, stems, and cobs) of different maize varieties. The study was carried out under farmer conditions in Çöteli village of Elazığ province in the 2022 growing season. Four different maize varieties (Everest, Hido, DKC-6442 and P32W86) were used as material. Crude protein, crude cellulose, crude ash, neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL) contents were analysed in samples taken from leaves, stems, and cobs. Results showed that there were statistically significant differences ($p \leq 0.01$) among cultivars for all traits. The highest crude protein content in leaves was determined in Everest variety with 17.43%. The highest NDF and ADF contents in stems were determined in DKC-6442 with 76.41% and 47.13%, respectively. In cob, Everest variety stood out with high crude protein (9.59%), fiber and ash contents. The results obtained revealed that there were significant differences among maize varieties in terms of nutritional values of plant parts and pointed out the importance of appropriate variety and part selection in terms of improving feed quality.
Keywords: Maize, plant parts, nutritive value, NDF, ADF, silage quality

Introduction

Maize silage is a widely used feed source for dairy and beef cattle, known for its high energy content and fermentative characteristics (Carvalho et al., 2016; Krogstad and Bradford, 2023). It is produced by fermenting chopped whole maize plants in silos, which preserves the nutritional value of the crop for extended periods. Maize silage plays a crucial role in ruminant nutrition, but its quality and nutritional value can be influenced by various factors (Krogstad and Bradford, 2023). It is preferred for silage due to its softness, high starch content, and sufficient soluble sugars required for proper ensiling (Karnatam et al., 2023). In conclusion, while maize silage remains a valuable feed source for animal production, ongoing research focuses on improving its quality and sustainability. This includes developing maize hybrids specific for silage production, considering traits such as dry matter yield, nutrient yield, and cell wall digestibility (Karnatam et al., 2023).

Maize plant parts, including stems, leaves, and cobs, exhibit varying rates of growth and feed quality characteristics as the plant matures. These differences have significant implications for forage production and utilization. The leaf-to-stem mass ratio decreases as maize plants mature, with leaf mass decreasing and stem mass increasing in the basal segment. In maize, the cob: stover ratio ranges from 0.14 to 0.25 at high nitrogen fertilizer levels, with cob yield increasing linearly with grain yield (Halvorson and Johnson, 2009). Interestingly, the feed quality of different plant parts varies significantly. Leaf tissue generally has higher crude protein (CP) and *in vitro* dry matter digestibility (IVDMD) compared to stem tissue. For example, at early head emergence in warm-season grasses, leaf and stem CP levels were 9.7% and 4.3%, respectively, while IVDMD was 60.4% for leaves and 50.0% for stems (Griffin and Jung, 1983). The decline in CP, IVDMD, and phosphorus with maturation is less pronounced in leaf tissue compared to stems (Griffin and Jung, 1983). In conclusion, the relative proportions and quality of plant parts change as maize matures, with leaves generally maintaining higher nutritional value than stems. The cob component becomes increasingly significant as the plant develops. These changes in plant part ratios and quality are crucial considerations for optimizing forage production and utilization in livestock systems. Changes in plant part ratios are affected by agricultural practices and vary greatly according to varieties. The aim of this study is to determine the nutritional properties of some parts of different maize varieties.

Materials and Methods

The research was carried out in a farmer's field in Çöteli Village of Elazığ province center in the growing season of 2022. ‘P32W86’ obtained from Pioneer Seeds, “DKC-6442” obtained from Monsanto Company ‘DKC-6442’ obtained from Monsanto Company. and ‘Hido’ and ‘Everest’ obtained from May-Agro Seeds were used as materials.

The province of Elazığ, where the research was conducted, has a continental climate; the winter season is cold and rainy, and the summer season is hot and dry. According to the data of Elazığ Regional Directorate of Meteorology, the temperature, precipitation, and relative humidity averages and long-term averages for the year 2022 are presented in Table 1.

Table 1. Some climatic data of Elazığ province covering long years (1939-2021) and vegetation period of the research year

Months	Temperature (°C)		Precipitation (mm)		Relative Humidity (%)	
	2022	Long Term	2022	Long Term	2022	Long Term
July	27.1	28.0	0.0	0.96	30.7	28.4
August	29.7	28.2	0.1	2.63	26.6	27.8
September	23.7	23.8	4.1	6.06	30.6	31.4
October	15.6	16.8	20.0	19.67	52.3	48.8
Mean/Total	**24**	**24.2**	**24.2**	**29.3**	**35**	**34.1**

During the period of the study, the average temperature was recorded as 24 °C, total rainfall as 24.2 mm, and average relative humidity as 35%. These data are close to the long-term averages (Table 1). The textural structure of the soil of the experimental land is in the loamy texture class. The pH of the soil is slightly alkaline with 7,78. It is moderate in terms of lime (10,64%), insufficient in organic matter (0,42%), and rich in available phosphorus (21.36 kg/ha P_2O_5) (Aydın and Sezen, 1995).

The research was carried out according to the randomized block design with three replications under second crop conditions. The 4 maize varieties were sown in a total of 12 plots. The row spacing was 70 cm and the row spacing was 15 cm. The sowings were made manually on 7 July 2022 on the previously prepared and levelled seed bed. After sowing, 35 kg of DAP base fertilizer was applied to all plots at a rate of 6.3 kg nitrogen and 16.1 kg P_2O_5 per decare.

After the sowing process was completed, a sprinkler irrigation system was installed in the trial area to ensure germination of the seeds. Irrigation times were determined according to phenological observations, and each irrigation was carried out for an average of 3 hours. Weed control was carried out manually until the plants reached the 3-5 leaf stage, after which the weed control was continued using a hand hoe. The last hoeing was carried out when the plants reached a height of 50-60 cm, and at this stage, throat filling was carried out. After the throat filling process, a drip irrigation system was installed in a line between every two rows. Each irrigation with the drip irrigation system was carried out under 2 bar pressure and for an average of 6 hours. In addition, 15 kg of Urea fertilizer was applied through the drip irrigation system to provide 6.9 kg of pure nitrogen per decare. Top fertilizer was applied by drip irrigation with 20 kg of Urea fertilizer to provide 9.2 kg of pure nitrogen per decare.

The plants were harvested on 22 October, 90-100 days after the emergence of the seeds at the dough stage. Observations were carried out on 10 plants selected from 2 rows in the center of each plot consisting of 4 rows in each plot. The cob, leaf and stem parts of the plants selected from each plot were separated and weighed separately; grain yield was calculated with the total average of these values, and cob, leaf and stem ratios were determined by proportioning these values to total plant weight (Seydoşoğlu and Saruhan, 2017; Anonymous, 2018). The cob, leaf and stem parts of the plants were placed in separate paper bags and dried in a drying cabinet at 70°C (until reaching constant weight) and weighed to determine dry cob, dry leaf, dry stem and dry plant weights (Anonymous, 2019). The crude ash content of the silage samples was determined by burning them in a muffle furnace at 550 °C for 8 hours (AOAC, 1990). The Kjeldahl method was used to determine the nitrogen (N) content of the silages. The crude protein ratio was calculated with the Nx6.25 formula (AOAC, 1990). Crude fiber, ADF, ADL, and NDF were done using the ANKOM Tech methods (2017).

Statistical analysis

The findings obtained as a result of the research were subjected to variance analysis according to the randomized block experimental design using the SAS (SAS Inst., 1999) package program. The LSD test was used to determine whether the difference between the means was significant.

Result and Discussion

The results of biochemical analyses of the leaves of maize varieties are presented in Table 2. Statistically significant differences were observed among the varieties in terms of crude protein content ($p \leq 0.01$). The highest crude protein ratio was determined in Everest variety with 17.43%, followed by P32W86 with 16.70%. The lowest value was determined in DKC-6442 variety with 15.30%. Crude ash content was highest in P32W86 with 11.93% and lowest in DKC-6442 with 9.74%. In terms of NDF content, the highest value was observed in Hido with 61.54% and the lowest value was observed in P32W86 with 58.61%. ADF content was

similar among the varieties, the highest value was determined in Everest with 34.59% and the lowest value was determined in DKC-6442 with 33.68%. In terms of ADL content, the lowest value was recorded in DKC-6442 with 4.46%, and the highest value was recorded in Everest with 5.04%.

Table 2. Some biochemical properties of maize cultivars' leaves

Cultivars	Crude Protein (%)	Crude Fiber (%)	Crude Ash (%)	NDF (%)	ADF (%)	ADL (%)
Everest	17.43a	29.68a	10.58b	60.12b	34.59a	5.04a
Hido	15.76b	29.51a	10.44b	61.54a	33.98b	4.66b
DKC-6442	15.30b	29.10b	9.74c	59.57c	33.68b	4.46c
P32W86	16.70a	29.55a	11.93a	58.61d	34.21ab	4.75b
Sg Dg	**	*	**	**	*	**
LSD	0.76	0.30	0.25	0.54	0.53	0.10

****:** p≤0.01; **Sg Dg:** Significant degree; **LSD:** least significant difference; **NS:** non-significant

The results of biochemical analyses of the stems of maize varieties are presented in Table 3. As a result of the analysis of the stems, statistically significant differences were found between the varieties in terms of crude protein content (p≤0.01). The highest crude protein content was found in Hido variety with 4.77% and the lowest content was found in DKC-6442 with 3.65%. NDF content was lowest in Everest with 69.37% and highest in DKC-6442 with 76.41%. Similarly, ADF content was lowest in Everest with 42.25% and highest in DKC-6442 with 47.13%. ADL content was highest in DKC-6442 with 6.07% and lowest in Everest with 5.27%. In terms of crude fiber and crude ash contents, some differences were observed among the varieties; Hido variety had the highest crude cellulose content with 37.41% and stood out with 5.88% crude ash content.

Table 3. Some biochemical properties of maize cultivars' stems

Cultivars	Crude Protein (%)	Crude Fiber (%)	Crude Ash (%)	NDF (%)	ADF (%)	ADL (%)
Everest	4.55a	33.92	5.29b	69.37c	42.25b	5.27c
Hido	4.77a	37.41	5.88a	75.20a	45.69a	5.39bc
DKC-6442	3.65c	28.16	5.09b	76.41a	47.13a	6.07a
P32W86	3.98b	36.69	5.27b	72.48b	45.88a	5.46b
Sg Dg	**	NS	**	**	**	**
LSD	0.26	16.40	0.37	2.67	1.47	0.18

****:** p≤0.01; **Sg Dg:** Significant degree; **LSD:** least significant difference; **NS:** non-significant

The results of biochemical analyses of cobs of maize varieties are presented in Table 4. The crude protein content of the cobs varied significantly among the varieties (p≤0.01). The highest crude protein content was found in Everest variety with 9.59% and the lowest was found in Hido variety with 7.75%. Crude cellulose content was highest in Everest variety with 23.29% and lowest in Hido variety with 10.56%. Crude ash content was highest in Everest variety with 3.00% and lowest in DKC-6442 variety with 1.69%. A similar trend was observed in terms of NDF and ADF ratios; Everest variety had the highest ratios in these values (55.40% and 26.72%, respectively), while these ratios remained at very low levels in DKC-6442 and

Hido varieties. ADL ratio showed a statistical difference among the varieties and was highest in Everest with 2.02% and lowest in P32W86 with 1.77%.

Table 2. Some biochemical properties of maize cultivars' cobs

Cultivars	Crude Protein (%)	Crude Fiber (%)	Crude Ash (%)	NDF (%)	ADF (%)	ADL (%)
Everest	9.59a	23.29a	3.00a	55.40a	26.72a	2.02a
Hido	7.75c	10.56b	2.26b	26.14c	13.23b	1.86b
DKC-6442	8.12c	10.78b	1.69c	26.10c	13.55b	1.82b
P32W86	8.83b	11.48b	1.87c	27.93b	14.16b	1.77b
Sg Dg	**	**	**	**	**	*
LSD	0.47	0.97	0.19	1.25	1.23	0.14

****:** p≤0.01; **Sg Dg:** Significant degree; **LSD:** least significant difference; **NS:** non-significant

In this study, the nutritional values of leaf, stem and cob parts of four different maize varieties were analysed in detail. The results revealed that there were significant differences in nutritional values between the varieties and plant parts. Especially, high crude protein ratios and relatively low NDF and ADF values in leaf parts indicate that this part is more advantageous in terms of feed quality. Similarly, cobs, with moderate protein and low ADL values, offer a content that can increase digestibility in ruminant nutrition. On the other hand, higher fibre ratios (especially NDF and ADF) in the stalks indicate that this part has a limiting effect on digestibility. It is reported that different parts of maize vary in terms of fiber and protein content (Kaplan et al., 2016). It was reported that there were differences in protein and fibre ratios between the plant parts and that the leaf parts were more advantageous, especially in terms of digestibility and relative feed value (Kaplan et al., 2014).

Conclusion

In this study, some biochemical properties of the leaf, stem, and cob parts of four different maize varieties were evaluated. The findings revealed that the nutritional values of the plant parts showed significant differences depending on both plant part and variety. Leaves had higher crude protein content and lower fiber content, while stems had higher NDF and ADF content, which negatively affected digestibility. Cobs, on the other hand, were found at a level between leaves and stems in terms of protein and fiber contents and gave positive results in some varieties. Especially Everest variety stood out in terms of feed quality with both high crude protein and balanced fiber composition. On the other hand, DKC-6442 cultivar showed lower digestibility due to high fiber content in the stem.

Based on these results, not only the total yield but also the nutritional value of individual plant parts should be taken into consideration in the selection of maize varieties to be used in silage and forage production. In order to improve feed quality, it is important to prefer varieties with high crude protein content and low fiber (NDF and ADF) ratios. In addition, in future studies, not only chemical composition but also parameters such as fermentation quality, in vitro digestibility and effects on animal performance should be examined. Such studies can be repeated under different climatic and soil conditions, and the performance of the varieties against environmental factors can be revealed more comprehensively. Finally, more balanced and effective rations should be prepared by considering the nutritional value of not only cobs but also other plant parts such as leaves and stems in feed formulations.

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FDM YÖNTEMİ İLE ÜRETİLEN PLA NUMUNELERİN İŞLEM PARAMETRELERİNİN MEKANİK DAYANIMA ETKİSİNİN İNCELENMESİ

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ÖZET

Eklemeli imalat teknolojileri, malzemenin katman katman biriktirilerek ürün haline getirilmesi esasına dayanan, geleneksel üretim yöntemlerine alternatif olarak hızla gelişen ve yaygınlaşan bir üretim yaklaşımıdır. Özellikle düşük maliyetli üretim imkânı, tasarım esnekliği ve karmaşık geometrilerin kolaylıkla üretilebilmesi gibi avantajları sayesinde endüstriyel uygulamalarda giderek yaygınlaşmaktadır. Hızlı prototipleme yöntemlerinden biri olan Ergiyik Yığma Modelleme (Fused Deposition Modelling - FDM) tekniği en yaygın kullanılan eklemeli imalat yöntemlerinden biridir. FDM yöntemi, termoplastik filamentlerin katman katman eritilerek üst üste biriktirilmesi prensibiyle çalışır. Bu yöntem ile üretilen parçaların mekanik performansı ise; nozul çapı, katman kalınlığı ve doluluk oranı gibi baskı parametrelerine doğrudan bağlıdır. Bu çalışmada FDM yöntemi ile üretilen PLA numunelerde, üç farklı nozul çapı (0.2, 0.4, 0.6 mm), katman kalınlığı (0.05, 0.1, 0.2 mm) ve doluluk oranı (%60, %80 ve %100) değerlerinin mekanik dayanıma etkisi incelenmiştir. Tüm numuneler sabit 220 °C baskı sıcaklığında üretilmiş, her bir kombinasyon için çekme testleri uygulanarak maksimum yük (N) ve gerilme dayanımı (N/mm²) parametreleri değerlendirilmiştir. Testler sonucunda, 0.6 nozul çapı ile basılan numunelerin dayanımlarının daha yüksek olduğu belirlenmiştir. Genel olarak, nozul çapı arttıkça ve katman kalınlığı azaldıkça mekanik dayanım artmış; yüksek doluluk oranı ise tüm kombinasyonlarda pozitif etkiler göstermiştir. Malzemenin taşıyabileceği maksimum yük değeri en düşük 45.67 N olarak hesaplanmıştır ve bu değer 0.4 nozul çapı, %60 doluluk oranı ve 0.1 mm katman kalınlığı kombinasyonu ile elde edilmiştir. 0.6 nozul çapı, %100 doluluk oranı ve 0.1 mm katman kalınlığı ile basılan numunelerde maksimum yük değerinde (82.33N) %80 oranında artış gözlemlenmiştir. Gerilme dayanımı açısından değerlendirildiğinde, minimum ve maksimum değerler arasında yaklaşık %57 oranında bir artış elde edilmiştir. Bu bulgular, baskı parametrelerinin mekanik dayanım üzerinde belirleyici etkiler oluşturduğunu vurgulamaktadır.

Anahtar Kelimeler: Eklemeli İmalat, Eriyik Yığma Modelleme, Maksimum Yük, Gerilme Dayanımı

INVESTIGATION OF THE EFFECT OF PROCESS PARAMETERS ON THE MECHANICAL STRENGTH OF PLA SPECİMENS PRODUCED BY FDM

ABSTRACT

Additive manufacturing technologies are a rapidly developing and increasingly widespread production approach based on the principle of building up material layer by layer to form a final product, offering an alternative to traditional manufacturing methods. Due to its advantages such as low-cost production capability, design flexibility, and the ease of manufacturing complex geometries, it has become increasingly prevalent in industrial applications. Fused Deposition Modeling (FDM), one of the rapid prototyping techniques, is among the most widely used additive manufacturing methods. The FDM method operates based on the principle of extruding thermoplastic filaments layer by layer. The mechanical performance of the parts produced using this method is directly influenced by printing parameters such as nozzle diameter, layer thickness, and infill density. In this study, the effects of three different nozzle diameters (0.2, 0.4, 0.6 mm), layer thicknesses (0.05, 0.1, 0.2 mm), and infill densities (60%, 80%, 100%) on the mechanical strength of PLA specimens produced using the FDM method were investigated. All specimens were produced at a constant printing temperature of 220 °C, and tensile tests were performed for each parameter combination to evaluate the maximum load (N) and tensile strength (N/mm²). As a result of the tests, it was determined that the specimens printed with a 0.6 mm nozzle diameter exhibited higher mechanical strength. In general, mechanical strength increased with larger nozzle diameters and lower layer thicknesses, while higher infill densities had a consistently positive effect across all combinations. The lowest maximum load value was calculated as 45.67 N, which was observed in the specimen printed with a 0.4 mm nozzle diameter, 60% infill density, and 0.1 mm layer thickness. A maximum load value of 82.33 N was obtained from the specimen printed with a 0.6 mm nozzle, 100% infill, and 0.1 mm layer thickness, indicating an approximate 80% increase. In terms of tensile strength, an improvement of around 57% was recorded between the minimum and maximum values. These findings highlight the significant influence of printing parameters on the mechanical performance of FDM-printed parts.

Keywords: Additive Manufacturing, Fused Deposition Modeling (FDM), Maximum Load, Tensile Strength

1. GİRİŞ

Eklemeli imalat teknolojileri, son yıllarda üretim süreçlerinde köklü değişimlere yol açarak, tasarım özgürlüğü, düşük maliyet ve hızlı prototipleme gibi önemli avantajlar sunmaktadır. Özellikle karmaşık geometrilerin kolaylıkla üretilebilmesi, bu teknolojilerin savunma, otomotiv ve medikal sektörleri başta olmak üzere birçok alanda yaygın şekilde kullanılmasını sağlamıştır. Eklemeli imalat en basit tanımıyla dijital ortamda tasarlanmış üç boyutlu modellerin, bir malzemenin tabaka tabaka üst üste eklenmesiyle fiziksel bir nesneye dönüştürülmesini ifade eder [1-3].

Eklemeli imalat yöntemleri arasında, üretim kolaylığı ve maliyet etkinliği açısından en çok tercih edilen yöntemlerden biri FDM (Fused Deposition Modeling) yöntemidir. FDM, termoplastik malzemeden üretilen filamentin sıcak ekstrüder başlığında eritilerek katman katman baskı tablasına aktarılması esasına dayanmaktadır. [4-5]. Düşük ekipman maliyeti ve kullanım kolaylığı nedeniyle FDM yöntemi hem endüstriyel hem de akademik çalışmalarda en sık tercih edilen yöntemlerden biri olmuştur [6]. FDM yöntemiyle üretilen parçaların mekanik performansı, kullanılan malzeme türü kadar üretim parametrelerine de doğrudan bağlıdır. Nozul çapı, katman kalınlığı, baskı sıcaklığı, doluluk oranı ve baskı hızı gibi parametreler, katmanlar arası yapışma kalitesi ve iç yapı homojenliği üzerinde belirleyici rol oynamaktadır [7-8-9].

Fonksiyonel parçalar için mekanik özellikler kritik öneme sahip olduğundan, üretim parametrelerinin mekanik performans üzerindeki etkisinin incelenmesi kesinlikle gereklidir. Bu durum FDM yöntemi ile üretilen numunelerde mekanik özelliklerin incelenmesine dair çalışmalara yer verilmesine yol açmıştır [10-11].

Polilaktik asit (PLA), bitkisel kaynaklı bir biyopolimer olması nedeniyle eklemeli imalat teknolojilerinde yaygın olarak tercih edilen bir malzemedir. Yenilenebilir kaynaklardan (örneğin mısır nişastası veya şeker kamışı) üretilmesi ve biyobozunur yapısı, çevre dostu bir alternatif sunmasına olanak tanımaktadır [12].

Literatürde PLA malzemelerin FDM yöntemi ile baskılanması sürecince baskı parametrelerinin mekanik dayanıma etkisi ile ilgili çeşitli çalışmalar yer almaktadır. Bir çalışmada PLA malzeme kullanılarak FDM yöntemiyle üretilen numunelerde nozul çapı sabit tutularak sıcaklık ve doluluk oranlarının çekme dayanımı üzerindeki etkisi incelenmiştir. Bulgular, sıcaklık arttıkça katmanlar arası yapışmanın güçlendiğini ve çekme dayanımının %10 oranında arttığını göstermektedir [2]. Başka bir çalışmada Günay ve arkadaşları PLA+ numunelerde doluluk oranı, baskı hızı ve tarama açısı değişkenlerini değerlendirerek, en yüksek çekme dayanımının %100 doluluk, düşük baskı hızı ve 0/90° tarama açısıyla elde edildiğini tespit etmişlerdir. Bu çalışma, doluluk oranının %71.8 oranla en etkili parametre olduğunu ortaya koymuştur [13]. Chacón ve arkadaşları ise yaptıkları çalışmada, katman kalınlığının azaltılmasının ve baskı yöneliminin optimize edilmesinin çekme dayanımı üzerinde olumlu etkiler sağladığını belirtmişlerdir. Katman kalınlığı azaldıkça, katmanlar arası yapışmanın arttığı ve böylece mekanik performansın iyileştiği görülmüştür [9]. Sood ve arkadaşları, FDM sürecinde parametreler arasındaki etkileşimi incelemiş ve doluluk oranı, baskı yönelimi ve katman kalınlığının çekme dayanımı üzerinde karmaşık bir etkiye sahip olduğunu belirtmiştir. Çalışmalarında optimum parametre kombinasyonlarının belirlenmesinin önemine dikkat çekmişlerdir [14]. Popescu ve arkadaşları, nozuldan çıkan filamentin başlığa göre yönlenmesinin, katman birleştirme kabiliyetiyle doğrudan ilişkili olduğunu ve bu durumun mekanik dayanım üzerinde kritik rol oynadığını göstermiştir [15]. Bacak bir çalışmasında, PLA, ABS ve TPU gibi üç farklı malzemede %30 ve %70 doluluk oranlarını karşılaştırmış ve yüksek doluluk oranının tüm malzemelerde çekme dayanımını önemli ölçüde artırdığını belirtmiştir. Özellikle PLA için sıcaklık artışı dayanımı yükseltirken, TPU'da tam

tersi bir düşüş yaşanmıştır [16]. Oğuz ve Şahin, farklı nozul çaplarının (0.4 mm, 0.6 mm ve 0.8 mm) sürünme davranışına etkisini incelemiş ve daha büyük nozul çaplarında sürünme miktarının azaldığını göstermiştir. Bu durum, rijitliğin nozul çapına bağlı olarak değiştiğini ortaya koymuştur [17]. Bir başka çalışmada İpekçi ve arkadaşları, 0.4 mm nozul ile farklı dolgu şekillerinde ürettikleri numunelerde, rectilinear desenin %15 daha yüksek çekme dayanımı sunduğunu rapor etmişlerdir [18]. Toprak tarafından yapılan çalışmada ise büyük nozul çaplarının, daha geniş ekstrüzyon yolları oluşturarak katmanlar arası bağ dayanımını artırdığı ve dolayısıyla genel mekanik performansı iyileştirdiği ifade edilmiştir [19]. Alafaghani ve arkadaşları, FDM ile üretilen numunelerde baskı parametrelerinin mekanik özellikler üzerinde önemli etkileri olduğunu ortaya koymuşlardır. Özellikle ekstrüzyon sıcaklığının ve katman kalınlığının artırılması ile mekanik dayanımda iyileşme sağlandığı, doluluk oranının ise çekme dayanımı üzerinde belirgin bir etkisi olduğu belirtilmiştir [20].

Yapılan literatür incelemeleri sonucunda, baskı parametrelerinin FDM yöntemiyle üretilen parçaların mekanik dayanımı üzerinde belirleyici etkiler oluşturduğu; uygun parametre kombinasyonlarının seçilmesinin ise ürünün dayanım, rijitlik ve yüzey kalitesi gibi performans kriterlerini doğrudan iyileştirdiği anlaşılmaktadır. Literatürde katman kalınlığı, doluluk oranı, baskı hızı gibi parametrelerin ürünün mekanik özelliklerine etkisinin kapsamlı bir şekilde incelendiği fakat nozul çapı ile ilgili çalışmaların kısıtlı olduğu görülmüştür. Bu çalışmada, üç farklı nozul çapı (0.2 mm, 0.4 mm, 0.6 mm), üç farklı katman kalınlığı (0.05 mm, 0.1 mm, 0.2 mm) ve üç farklı doluluk oranı (%60, %80, %100) kullanılarak sabit sıcaklıkta (220°C) üretilen PLA numunelerin çekme test sonuçları incelenmiş, baskı parametrelerinin maksimum yük ve gerilme dayanımı üzerindeki etkileri deneysel olarak değerlendirilmiştir.

2. MATERYAL VE METOT

Son yıllarda 3D yazıcılar endüstriyel üretimden prototip üretime kadar geniş bir yelpazede kullanılan önemli bir teknoloji haline gelmiştir. 3D yazıcılar dijital ortamda tasarlanmış modelleri fiziksel nesnelere dönüştürme yeteneğine sahip cihazlardır [21].
Bu çalışmada numune basımında şekil 1'de verilen BambuLab P1P marka 3 boyutlu yazıcı kullanılmıştır.

Şekil 1. Baskı Numunelerinde Kullanılan BambuLab P1P Model 3D Yazıcı [21] ve Basılan Numuneler

Baskı malzemesi olarak PLA+ filament kullanılmıştır. Tablo 1'de filamentin teknik özellikleri yer almaktadır.

Özellik	**Değer**
Malzeme Türü	PLA+ (Modifiye PLA)
Yoğunluk	1.21 g/cm³
Çekme Dayanımı	61 MPa
Çekme Modülü	3,600 MPa
Çekme Uzaması	%6
Eğilme Dayanımı	97 MPa
Eğilme Modülü	3,800 MPa
Darbe Dayanımı	7.5 kJ/m²
Baskı Sıcaklığı	210–230°C
Tabla Sıcaklığı	0–60°C
Filament Çapı	1.75 mm

Tablo1. PLA+ Filament Özellikleri [22]

Nozul çapı basılan parçaların boyutsal doğruluğunu, yüzey kalitesini ve mekanik özelliklerini etkileyen temel parametrelerden biridir. Farklı nozul çapları malzemenin akış hızını, yazıcının çözünürlük seviyesini ve katmanların ne kadar ince olabileceğini belirler. Bu nedenle yazıcıda kullanılacak nozul çapı doğru seçilmelidir. Çalışmanın temel amacı 3D yazıcıların üretim sürecinde nozul çapının mekanik dayanım üzerindeki etkilerini incelemektir. Çalışma kapsamında 0,2 mm, 0,4 mm ve 0,6 mm nozul çaplarının basılan parçaların gerilme dayanımı ve malzemenin taşıyabileceği maksimum yük değerleri üzerindeki etkileri analiz edilmiştir.

Şekil2. Çalışmada Kullanılan Nozzle Çapları

Deneyler numuneleri 220°C sabit sıcaklık altında üç farklı katman kalınlığı (0,05-0,1-0,2mm) ve üç farklı doluluk oranı (%60-%80-%100) ile basılmıştır. Tüm baskı parametre kombinasyonları için üçer adet numune üretilmiş; elde edilen mekanik test sonuçları ortalama değerler üzerinden değerlendirilerek deneysel sonuçların doğruluğu ve tekrarlanabilirliği sağlanmıştır. Toplamda 81 baskı numunesi alınmıştır ve her deney kombinasyonu için üç numunenin ortalaması alınarak testler sonucunda 27 numune karşılaştırılmıştır. Deneylerde kullanılan değişken parametreler Tablo 2'de gösterilmiştir.

Deney Parametreleri	
Nozzle Çapı	0,2-0,4-0,6 mm
Katman Kalınlığı	0,05-0,1-0,2 mm
Dolgu Yoğunluğu	%60-%80-%100

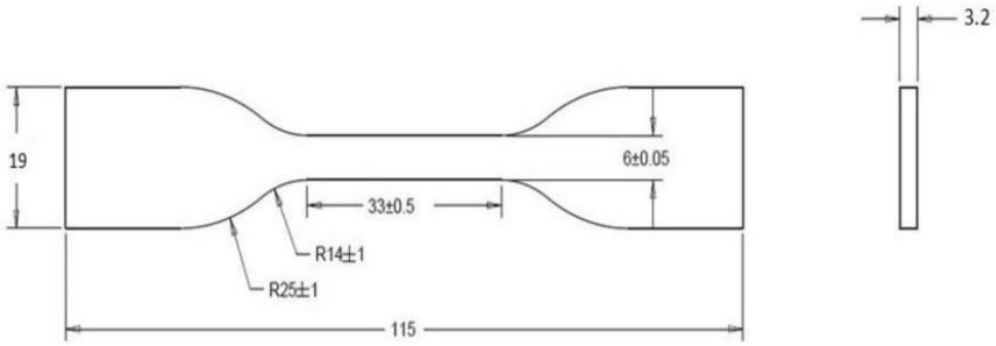
Tablo2. Basımda Kullanılan Değişken Parametreler

3D yazıcı için gerekli sabit parametreler literatürde yer alan çalışmalardan ve yazıcının kullanım kılavuzundan alınmıştır. Tablo 3'de çalışmada kullanılan sabit parametreler yer almaktadır.

Sabit Parametreler	
Katman Genişliği	0,22
Ütüleme	Ütüleme yok
Duvar Türü	Klasik Duvar Türü
Dolgu Deseni	Kafes-Doğrusal
Dolgu Açısı	45°C
Başlangıç Katmanı hızı	40mm/s
Etek Sayısı	0
Nozzle Sıcaklığı	220°C
Plaka Sıcaklığı	35°C

Tablo3. Basımda Kullanılan Sabit Parametreler

Nozul çapının parçaların mekanik dayanımı üzerindeki etkilerini belirlemek amacıyla numunelere çekme testi uygulanmıştır. Üretilen numuneler, ASTM D638-IV standardına uygun şekilde hazırlanmıştır. Bu standart, termoplastik malzemelerin çekme özelliklerini belirlemek için kullanılan uluslararası bir standarttır ve özellikle malzeme davranışının doğru bir şekilde değerlendirilmesi için önemlidir. Şekil 3'de ASTM D638 standardına ait bir teknik resim bulunmaktadır, bu resim, test sırasında kullanılan numunenin geometrik yapısını ve çekme testinin düzenini göstermektedir.



Şekil 3.ASTM D638 standardına ait teknik çizim

Çekme testlerinde Şekil 4'de verilen Gazi Üniversitesi Teknoloji Fakültesi İmalat Mühendisliği Bölümü bünyesinde bulunan UTEST Marka çekme test cihazı kullanılmıştır. Cihaz özellikleri tablo 4'de yer almaktadır.

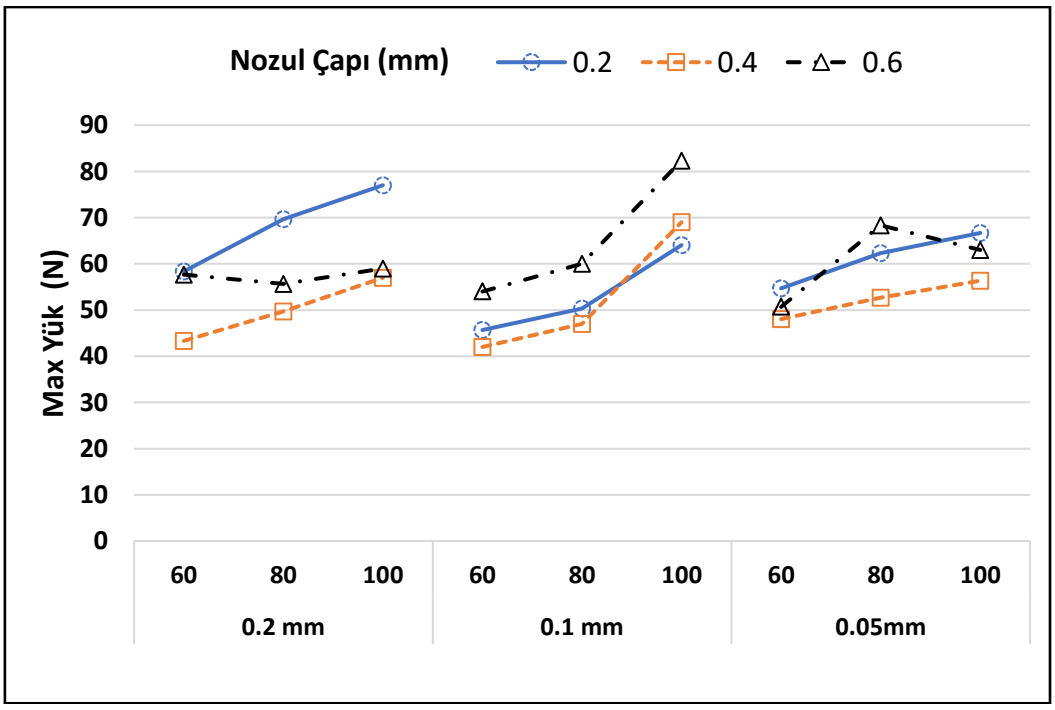
Cihaz İsmi	**Çekme Cihazı (UTEST UTM-100)**
Çekme kapasitesi	10 kN
Çekme Max Boyu	500 mm
Extensometer	Var

Tablo4. Çekme Cihazı Özellikleri

Şekil4. Çekme Test Cihazı

3. SONUÇLAR VE DEĞERLENDİRME

Çekme testlerinde numunelere uygulanan maksimum yük (N) ve elde edilen gerilme dayanımı (N/mm²) değerleri ölçülerek değerlendirilmiştir. Testler sırasında elde edilen veriler, nozul çapı, katman kalınlığı ve doluluk oranının mekanik dayanım üzerindeki etkilerini ortaya koymak amacıyla analiz edilmiştir. Testler sonucunda nozul çapı, katman kalınlığı ve doluluk oranı ile maksimum yük (Şekil 5) ve gerilme dayanımı (Şekil 6) arasındaki ilişkiler detaylı bir şekilde incelenmiştir.



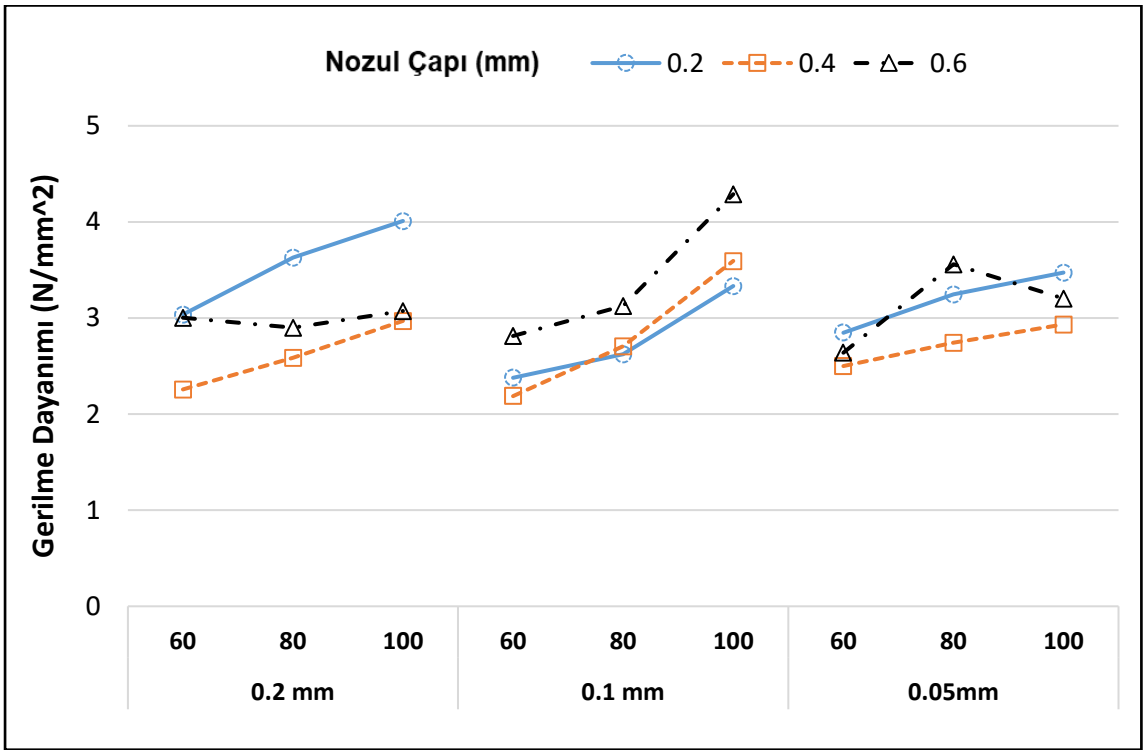
Şekil5. Maksimum Yük Sonuçları

0.2 mm nozul çapında en yüksek yük taşıma kapasitesi 0.2 mm katman kalınlığında ve %100 doluluk oranında görülmüştür. En düşük yük taşıma kapasitesi 0.1 mm katman

kalınlığında görülmüştür. 0.4 mm Nozul Çapında genel olarak yük taşıma kapasitesi düşük çıkmıştır. Bu durum, bazı çalışmalarda ara nozul çaplarının (0.4 mm) yetersiz malzeme yayılımı nedeniyle dezavantajlı olabileceğini göstermektedir [14]. 0.6 mm Nozul Çapında ise en yüksek yük değerleri burada görülmüştür. Literatürde de 0.6 mm nozul çapının yüksek hacimli ve sağlam yapı üretiminde avantajlı olduğu belirtilmiştir [6].

Katman kalınlığı azaldıkça malzemenin taşıyabileceği maksimum yük değeri artmıştır. 0.05 mm katman kalınlığı yüksek mukavemet sağlamıştır. Bu durum, yüksek malzeme akışıyla birlikte ince katman kalınlığı kullanıldığında, daha sıkı katman bağları oluştuğunu göstermektedir. Genel olarak dolgu oranı arttıkça maksimum yük değeri artmıştır. Bu, dolgun yapının içsel mukavemeti artırmasından kaynaklanmaktadır.

Yüksek doluluk oranı ve ince katman kalınlığı tüm nozul çaplarında malzemenin taşıyabileceği maksimum yük değerini artırmıştır. Daha büyük nozul çapları, daha geniş ekstrüzyon hatları oluşturarak katmanlar arası yapışmayı iyileştirmekte ve bu da parçanın mekanik dayanımını artırmaktadır. Büyük nozul çapları, daha hızlı baskı imkânı sağlar, çünkü daha fazla malzeme aynı anda ekstrüde edilir. Böylelikle üretim verimliliğini artırmaktadır [24]. Çalışma göstermektedir ki, nozul çapı büyüdükçe malzeme dağılımı daha homojen olabilir, bu da Maksimum Yük kapasitesini artırır. Ancak bu durum katman kalınlığı ile doğru orantılı seçilmelidir.



Dolgu oranı arttıkça gerilme dayanımı değeri artmıştır. 0.4 mm nozul çapı, diğer ikisine kıyasla daha zayıf performans sergilemiştir. 0.6 mm nozul çapında ise 0.4 mm'de olduğu gibi katman kalınlığının azalması ile gerilme dayanım değeri artış göstermiştir. Daha ince katman kalınlığı (0.05 mm), daha fazla bağlanma yüzeyi sunduğu için gerilme dayanımını artırmaktadır. Ancak aşırı ince katmanlar, iç gerilimlere ve baskı sırasında hatalara neden olabilir. Katmanlar arası bağ dayanımı, gerilme dayanımını etkileyen en önemli faktördür. İnce katman ve yüksek doluluk oranı, bağ yapısını güçlendirir [14]. Sonuç olarak daha büyük nozul çapı ve ince katman kullanımının iyi sonuç verdiği görülmüştür.

Yapılan deneysel çalışmalar sonucunda, nozul çapı, katman kalınlığı ve iç doluluk oranı gibi FDM parametrelerinin mekanik dayanım üzerinde doğrudan ve etkileşimli etkiler yarattığı belirlenmiştir. Elde edilen verilere göre, 0.2 mm nozul çapı, yüksek katman hassasiyeti ve daha iyi katmanlar arası yapışma sağlaması sayesinde gerilme dayanımı açısından genellikle en iyi sonuçlar vermiştir. Bununla birlikte, 0.6 mm nozul çapı, özellikle 0.1 mm katman kalınlığı ve %100 doluluk oranı ile birlikte kullanıldığında, maksimum yük taşıma kapasitesi açısından üstün performans sergilemiştir. Sonuç olarak, mekanik performansı optimize etmek için tek bir parametreden ziyade, parametre kombinasyonlarının dikkatle değerlendirilmesi gerektiği ortaya konmuştur.

Teşekkür

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A MATHEMATICAL METHOD FINDING THE VIBRATION FREQUENCIES OF A VISCOELASTIC BEAM

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ABSTRACT
Viscoelastic materials are materials that exhibit both viscous (time dependent) and elastic properties. They are both resistant to deformation and lose energy when deformed. These materials are used in many fields today, such as contact lenses, biomechanics, suspension systems, vibration dampers, seismic isolation of buildings and bridge materials. Mathematical models such as Maxwell and Kelvin-Voigt are used to understand and model the behavior of viscoelastic materials. These models help in predicting the stress and strain responses of materials. Finding the vibration frequencies of beams made of viscoelastic materials is of great importance in the design and manufacture of such beams. When the beam exhibits viscous behavior, the deformation increases with time when load is applied and the deformation returns with time when the load is removed. It is aimed to develop a general method to rationally find and calculate the vibration frequencies of these materials for different boundary conditions. Viscoelastic behavior is a structure used to analyze the behavior under time-varying loads and deformations. First, the equation of motion and boundary conditions of the problem are analyzed. The behavior of such beams usually requires time-dependent analysis. With these boundary conditions, the equation of motion is planned to be solved and the role of the transient frequencies in sizing will be investigated. The results obtained will be compared with the results found in the literature and the accuracy of the model will be discussed.
Keywords: Vibration · viscoelastic · beam

1. Introduction

Viscoelastic materials, which simultaneously exhibit both elastic and viscous behavior, have become integral to modern engineering and material science applications. These materials resist deformation like elastic solids while also dissipating energy over time as viscous fluids do. Due to their unique mechanical characteristics, viscoelastic materials are extensively employed in a wide range of applications including contact lenses, biomechanical devices, automotive suspension systems, vibration dampers, and in the seismic isolation of structural elements such as buildings and bridges.

Understanding the dynamic behavior of viscoelastic structures—particularly their response to time-dependent loads—is crucial for ensuring both functionality and longevity in design. Mathematical models such as the Maxwell and Kelvin-Voigt models are widely used to represent and simulate the time-dependent stress-strain relationship of these materials. These models enable engineers and researchers to estimate the deformation behavior under various mechanical conditions and to predict vibration responses [1].

In structural applications, determining the natural vibration frequencies of viscoelastic beams is of particular importance. When subjected to external loads, viscoelastic beams exhibit time-dependent deformation characteristics: deformation increases over time under constant loading and gradually recovers when the load is removed. This behavior necessitates specialized approaches for accurate vibrational analysis, especially under varying boundary conditions.

In this context, some studies on viscoelastic materials and vibration in the literature are given below.

Arda [2] has investigated the torsional vibration of nanorods using both the Kelvin–Voigt and Maxwell viscoelastic models and has highlighted the differences between these two approaches. Kadioğlu et al. [3] have examined the torsional vibration behavior of viscoelastic nanotubes under viscoelastic boundary conditions. In addition, Tariq et al. [4] have explored the torsional vibrations of viscoelastic nanotubes based on the Lam's strain gradient theory and have demonstrated the advantages of machine learning in predicting torsional vibration characteristics. El-Borgi et al. [5] have studied the torsional vibration of nanotubes by employing the Kelvin–Voigt viscoelastic model in conjunction with the nonlocal strain and velocity gradient theory. Kadioğlu and Yayli [6] have analyzed the axial vibration of viscoelastic nonlocal beams under elastic boundary conditions. Lei et al. [7] have investigated the dynamic behavior of nanobeams using the nonlocal theory combined with the Generalized Maxwell viscoelastic model. They have also conducted a vibration analysis of nonlocal Timoshenko beams using the Kelvin–Voigt viscoelastic model. Eltaher et al. [8] have performed a vibration analysis of perforated viscoelastic nonlocal Timoshenko beams. Zhen et al. [9] have explored the dynamic behavior of viscoelastic nanobeams under various magnetic influences by employing the nonlocal strain gradient theory. Lastly, Zhang et al. [10] have examined the viscoelastic beams under axial pre-tension, taking into account both nonlocal and surface effects. More studies can be added to these studies [11–23].

The present study aims to develop a general methodology to compute the vibration frequencies of viscoelastic beams for different boundary scenarios. By formulating and solving the equation of motion under specific conditions, this work investigates how transient frequencies influence beam design and sizing. The theoretical outcomes will be validated through comparisons with existing results in the literature, thereby assessing the accuracy and reliability of the proposed model.

2. Formulation of the Vibration Problem

The moment (M) and shear force (V) functions of the Euler Bernoulli beam theory are defined as follows [22].

$$M = -EI\frac{\partial^2\varphi(x,t)}{\partial x^2} \quad (1)$$

$$V = -EI\frac{\partial^3\varphi(x,t)}{\partial x^3} \quad (2)$$

Here E represents the modulus of elasticity, I the moment of inertia and φ the vertical displacement function.

The equation of motion for this theory is obtained as follows [22].

$$EI\frac{\partial^4\varphi(x,t)}{\partial x^4} = \rho A\frac{\partial^2\varphi(x,t)}{\partial t^2} \quad (3)$$

Here ρ is the density and A is the cross-sectional area.

The above equation of motion is valid for a beam with homogeneous isotropic and elastic behavior. When viscoelastic material behavior is added to these equations of motion with shear force and moment function, these equations are transformed into the following form.

$$M = -\left(1 + c_d\frac{\partial}{\partial t}\right)EI\frac{\partial^2\varphi(x,t)}{\partial x^2} \quad (4)$$

$$V = -\left(1 + c_d\frac{\partial}{\partial t}\right)EI\frac{\partial^3\varphi(x,t)}{\partial x^3} \quad (5)$$

$$\left(1 + c_d\frac{\partial}{\partial t}\right)EI\frac{\partial^4\varphi(x,t)}{\partial x^4} = -\rho A\frac{\partial^2\varphi(x,t)}{\partial t^2} \quad (6)$$

Here c_d is defined as the viscous damping coefficient.

3. Analytical Solution Approach

In order to solve the problem, differentials with more than one variable must first be transformed into a single variable form, for which the following definition is frequently used in the literature [3].

$$\varphi(x,t) = e^{i\omega t}\bar{\varphi}(x) \quad (7)$$

Here ω represents the angular frequency.

In this case, the equation of motion and the shear force and moment functions are obtained as follows.

$$(1 + i\omega c_d)EI\frac{d^4\bar{\varphi}(x)}{dx^4} - \rho A\omega^2\bar{\varphi}(x) = 0 \quad (8)$$

$$M = (1 + i\omega c_d)EI\frac{d^2\bar{\varphi}(x)}{dx^2} \quad (9)$$

$$V = (1 + i\omega c_d)EI\frac{d^3\bar{\varphi}(x)}{dx^3} \quad (10)$$

In order to solve the vibration problem, the vertical displacement function is chosen as Fourier sinus series as follows [1].

$$\alpha_m = \frac{m\pi}{L} \quad (11)$$

$$\bar{\varphi} = \sum_{m=1}^{\infty} A_m \mathrm{Sin}[\alpha_m x] \quad (12)$$

Here L represents the length of the beam. A_m is defined as the Fourier coefficient. The higher order derivatives of this series are also obtained with the help of Stokes' Transforms as follows [1].

$$\frac{d\bar{\varphi}}{dx} = \frac{\bar{\varphi}_L - \bar{\varphi}_0}{L} + \sum_{m=1}^{\infty} \left(\frac{2}{L} (\bar{\varphi}_L (-1)^m - \bar{\varphi}_0) + \alpha_m A_m \right) \mathrm{Cos}[\alpha_m x] \tag{13}$$

$$\frac{d^2\bar{\varphi}}{dx^2} = -\sum_{m=1}^{\infty} \alpha_m \left(\frac{2}{L} (\bar{\varphi}_L (-1)^m - \bar{\varphi}_0) + \alpha_m A_m \right) \mathrm{Sin}[\alpha_m x] \tag{14}$$

$$\frac{d^3\bar{\varphi}}{dx^3} = \frac{\bar{\varphi}''_{\mathrm{L}} - \bar{\varphi}''_0}{L} + \sum_{m=1}^{\infty} \left(\frac{2}{L} (\bar{\varphi}''_{\mathrm{L}} (-1)^m - \bar{\varphi}''_0) - {\alpha_m}^2 \left(\frac{2}{L} (\bar{\varphi}_L (-1)^m - \bar{\varphi}_0) + \alpha_m A_m \right) \right) \mathrm{Cos}[\alpha_m x] \tag{15}$$

$$\frac{d^4\bar{\varphi}}{dx^4} = -\sum_{m=1}^{\infty} \alpha_m \left(\frac{2}{L} \left(\bar{\varphi}''_{\mathrm{L}} (-1)^m - \bar{\varphi}''_0 \right) - {\alpha_m}^2 \left(\frac{2}{L} (\bar{\varphi}_L (-1)^m - \bar{\varphi}_0) + \alpha_m A_m \right) \right) \mathrm{Sin}[\alpha_m x] \tag{16}$$

Where $\bar{\varphi}_L$ and $\bar{\varphi}_0$ are the vertical displacement for x=L and x=0. $\bar{\varphi}''_{\mathrm{L}}$ and $\bar{\varphi}''_0$ are the values of the 2nd derivatives of the displacement function at these points for x=L and x=0. If these equations above are substituted in Equation 8, the Fourier coefficient is found as follows.

$$A_m = \frac{2(1 + i\omega c_d) EI \alpha_m (\alpha_m^2 \varphi_0 + (-1)^{1+m} \alpha_m^2 \varphi_L - \varphi''_0 + (-1)^m \varphi''_L)}{L(-\rho A \omega^2 + (1 + i\omega c_d) EI \alpha_m^4)} \tag{17}$$

When the boundary conditions in Figure 1 are included in the solution of the problem, Equation 10 can be written as follows. In addition, for this boundary condition $\bar{\varphi}''_{\mathrm{L}} = \bar{\varphi}''_0 = 0$.

$$K\bar{\varphi} = -(1 + i\omega c_d) EI \frac{d^3\bar{\varphi}(x)}{dx^3} \tag{18}$$

Here K represents the spring constants. For x=0, K_0 takes the value K_L for x=L.

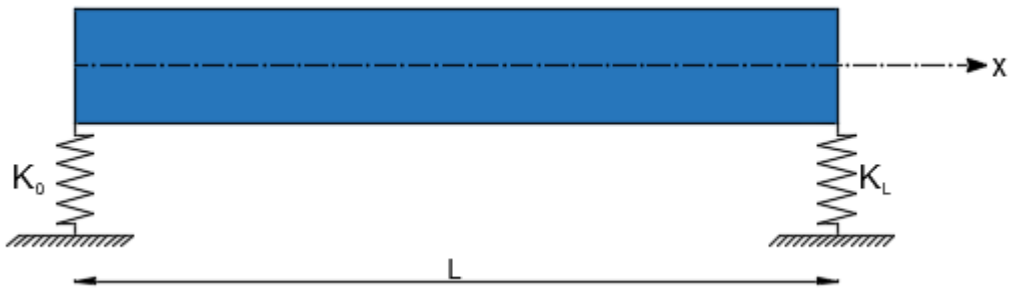

Fig. 1. Boundary conditions of viscoelastic beam

When Equation (18) is written separately for x=0 and x=L, two linear equations are obtained. These equations can be written in matrix form as follows.

$$\begin{pmatrix} \Phi_{11} & \Phi_{12} \\ \Phi_{21} & \Phi_{22} \end{pmatrix} \begin{pmatrix} \bar{\varphi}_0 \\ \bar{\varphi}_L \end{pmatrix} = 0 \tag{19}$$

$$\Phi_{11} = K_0 + \sum_{m=1}^{\infty} \frac{2Lm^2\pi^2(1+i\omega c_d)EI(-\rho A\omega^2)}{m^4\pi^4(1+i\omega c_d)EI + L^4(-\rho A\omega^2)} \quad (20)$$

$$\Phi_{12} = \sum_{m=1}^{\infty} -\frac{2(-1)^m Lm^2\pi^2(1+i\omega c_d)EI(-\rho A\omega^2)}{m^4\pi^4(1+i\omega c_d)EI + L^4(-\rho A\omega^2)} \quad (21)$$

$$\Phi_{21} = \sum_{m=1}^{\infty} -\frac{2(-1)^m Lm^2\pi^2(1+i\omega c_d)EI(-\rho A\omega^2)}{m^4\pi^4(1+i\omega c_d)EI + L^4(-\rho A\omega^2)} \quad (22)$$

$$\Phi_{22} = K_L + \sum_{m=1}^{\infty} \frac{2Lm^2\pi^2(1+i\omega c_d)EI(-\rho A\omega^2)}{m^4\pi^4(1+i\omega c_d)EI + L^4(-\rho A\omega^2)} \quad (23)$$

When the determinant of the above 2x2 matrix is taken and set equal to zero, the most general solution is obtained where the frequencies of a viscoelastic beam under elastic boundary conditions can be obtained. In addition, it is possible to obtain results for simply supported beams by giving infinitely large values to the spring constants, while it is possible to obtain results for a completely free beam by choosing very small values.

4. Insights from the Frequency Calculations

In this section, the results obtained from the analysis of vibrations of viscoelastic beams are presented and evaluated. The material properties are defined as E=30 MPa, ρ=1 gr/cm^3, and Poisson's ratio μ=0.3. A rectangular cross-section is assumed for the beam, with both the width (b) and depth (h) set to 1 m. Unless otherwise specified, the depth-to-length ratio of the beam (L/h) is taken as 10 throughout the study.

In addition, the frequency and the viscous damping coefficient can be nondimensionalized as follows.

$$\lambda = \omega L^2 \sqrt{\frac{\rho A}{EI}} \quad (24)$$

$$\eta = \frac{c_d}{L^2\sqrt{\frac{\rho A}{EI}}} \quad (25)$$

Here λ represents the dimensionless frequency and η the viscous damping parameter.

Table 1 displays the variation of the dimensionless frequencies as a function of the viscous damping parameter and the variation of L/h. It can be observed that for values of the viscous damping parameter greater than zero, the dimensionless frequencies are obtained as the sum of real and imaginary values. In this case, real values are considered to represent frequency and imaginary values represent damping.

On the other hand, no change is observed in the dimensionless frequency with the increase of L/h. This is due to the fact that inertial effects are not included in the equations of motion. It should also be known that the fact that the frequencies do not change means that the angular frequencies decrease as L/h increases. In fact, the stiffness of the beam reduces with the increment in L/h, so the beam exhibits a more flexible behavior.

Table 1. Variation of first mode dimensionless frequencies of beams with simple-simple (S-S) boundary conditions depending on L/h and η.

η	L/h				
	2	5	10	20	100
0	9.87	9.87	9.87	9.87	9.87
0.01	9.858+0.487i	9.858+0.487i	9.858+0.487i	9.858+0.487i	9.858+0.487i
0.02	9.821+0.974i	9.821+0.974i	9.821+0.974i	9.821+0.974i	9.821+0.974i
0.03	9.761+1.461i	9.761+1.461i	9.761+1.461i	9.761+1.461i	9.761+1.461i
0.04	9.675+1.948i	9.675+1.948i	9.675+1.948i	9.675+1.948i	9.675+1.948i
0.05	9.564+2.435i	9.564+2.435i	9.564+2.435i	9.564+2.435i	9.564+2.435i
0.06	9.427+2.922i	9.427+2.922i	9.427+2.922i	9.427+2.922i	9.427+2.922i
0.07	9.262+3.409i	9.262+3.409i	9.262+3.409i	9.262+3.409i	9.262+3.409i
0.08	9.068+3.896i	9.068+3.896i	9.068+3.896i	9.068+3.896i	9.068+3.896i
0.09	8.843+4.383i	8.843+4.383i	8.843+4.383i	8.843+4.383i	8.843+4.383i
0.1	8.584+4.87i	8.584+4.87i	8.584+4.87i	8.584+4.87i	8.584+4.87i

Figure 2 demonstrates the variation of the real and imaginary values of the dimensionless frequencies depending on the viscous damping parameter. As the viscous damping parameter grows, the real values of the dimensionless frequencies decline more than each range of viscous damping parameters. The imaginary values rise in a linear trend. It is considered that the steeper this linearity is, the greater the effect of the viscous damping parameter.

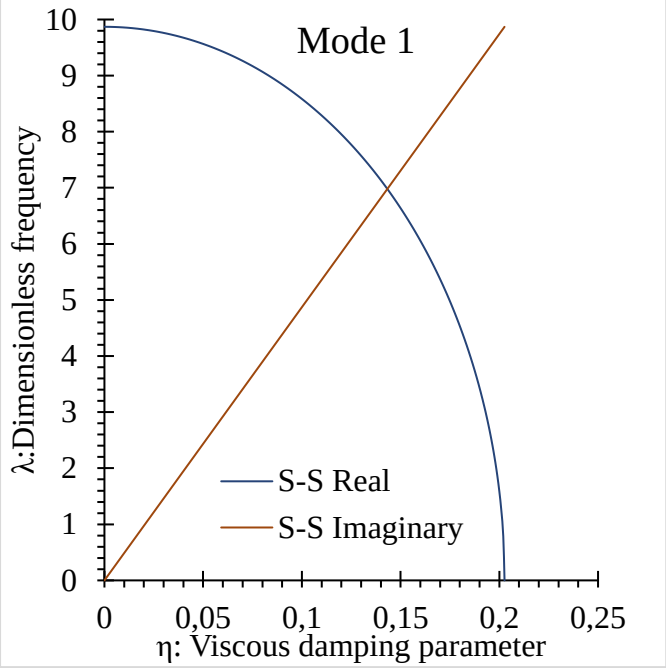

Fig. 2. Variation of dimensionless frequencies depending on the viscous damping parameter

In addition, it is observed in figure 3 that there is a relationship between these real and imaginary values. And this relationship mathematically yields a circle equation. This can be mathematically defined as follows.

$$\lambda_{ud}{}^2 = \lambda_{im}{}^2 + \lambda_{re}{}^2 \quad (26)$$

Where λ_{ud} is the undamped dimensionless frequencies, λ_{re} is the real value of the dimensionless frequency and λ_{im} is the imaginary value of the dimensionless frequency.

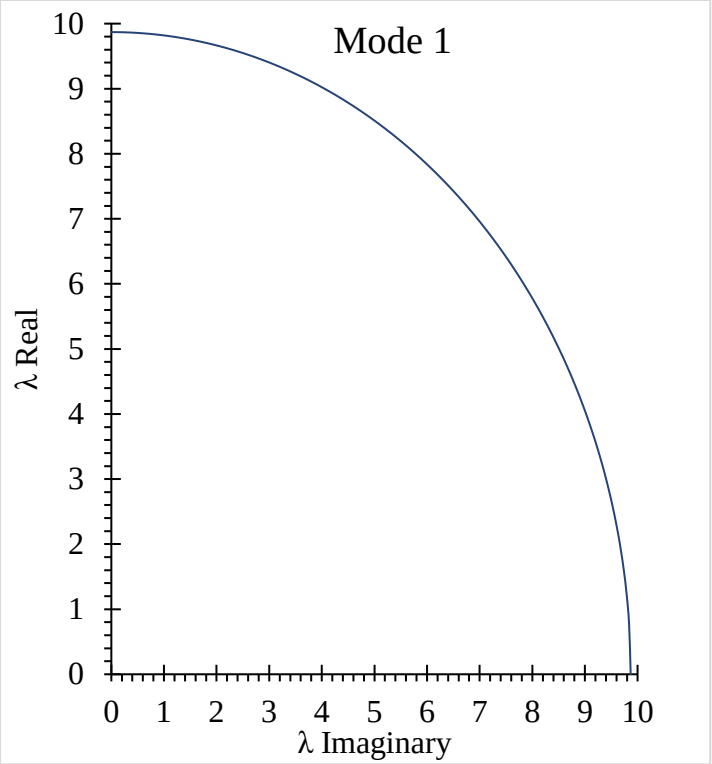

Fig. 3. Relationship between real and imaginary values of dimensionless frequencies

In conclusion, it is clear that damping has significant effects on the dynamic behavior of beams. Complex frequency values provide important theoretical insights. And with the method proposed in this study, the dynamic response of viscoelastic beams can be analyzed more realistically.

5. Concluding Remarks

In this study, a method for analyzing vibrations of viscoelastic beams under elastic boundary conditions is presented and investigated. In addition, the effect of viscous damping on the dimensionless frequencies is evaluated. The results obtained indicate that the frequencies become more complex as the viscous damping parameter increases; the real part is considered to represent the frequency and the imaginary part represents the damping. It has also been determined that the L/h ratio has no effect on the dimensionless frequencies, which is due to the neglect of inertial effects. A circular relationship between the real and imaginary frequency components is found and this relationship is described by the undamped frequency. As a result, it is believed that the proposed method can provide a more realistic analysis of the dynamic behavior of viscoelastic beams.

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FARKLI BOYUTLARDAKİ ALÜMİNYUM OKSİT ETKİSİNDE *Oreochromis niloticus*'DA DOKU BİRİKİMİNİN İNCELENMESİ

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Özet
Alüminyum (Al) doğada yaygın olarak bulunan bir element olup oksijen ve silisyumdan sonra yer kabuğunda en çok bulunan elementtir Bu araştırmada, Al_2O_3' in mikro ve nano boyutlarının 10 mg/L derişimlerinin 7 günlük süreyle etkisinde *O.niloticus*' un solungaç, karaciğer ve kas dokularındaki metal birikim düzeyleri belirlenmiştir. Dokulardaki alüminyum düzeyleri ICP-MS ile ölçülmüştür. Yürütülen bu araştırmada deneyler süresince mortalite gözlenmemiştir. Al_2O_3' in her iki formunun etkisinde incelenen dokularda kontrole oranla önemli düzeyde artış olduğu gözlenmiştir. Al_2O_3' in her iki formunun etkisinde dokular arasında 7 günlük etki süresi sonunda solungaç>karaciğer> kas şeklinde bir dizilim saptanmıştır.
Anahtar Kelimeler: Boyut, Mikro, Nano, Alüminyum, Birikim, *O. niloticus*

INVESTIGATION OF THE EFFECTS OF DIFFERENT SIZES OF ALUMINUM OXIDE ON TISSUE ACCUMULATION OF *Oreochromis niloticus*

Abstract
Aluminum (Al) is a widely occurring element in nature and is the most abundant element in the earth's crust after oxygen and silicon. In this study, metal accumulation levels in the gills, liver and muscle tissues of *O. niloticus* were determined under the influence of 10 mg/L concentrations of micro and nano sizes of Al_2O_3 for 7 days. Aluminum levels in the tissues were measured by ICP-MS. In this study, no mortality was observed during the experiments. It was observed that there was a significant increase in the tissues examined under the effect of both forms of Al_2O_3 compared to the control. At the end of the 7-day exposure period, the following relationship was found among the tissues in accumulating under the effect of both forms of Al_2O_3 as gill>liver>muscle.
Keywords: Size, Micro, Nano, Aluminum, Accumulation, *O. niloticus*

GİRİŞ

Mikropartiküller (MP) 1–1000 mm aralığında boyutlara sahip katı partiküllerdir, nanopartiküller ise 1–1000 nm aralığında katı partiküllerdir. Öte yandan, mikro ve nano partiküllerin çoğunluğu sırasıyla 100 mm ve 200 nm'den daha küçük partiküllerdir. Mikro ve nano partiküller arasındaki boyut farkından dolayı farklı toksikolojik etkilere yol açabilirler. Nanopartiküllerin biyolojik membranlardan ve dokulardan daha kolay geçebildiği bilinmektedir. Ancak mikropartiküller hücrelere ve dokulara kolayca nüfuz edemez (Kohane 2007; Mahato 2017).

Alüminyum (Al) doğada yaygın olarak bulunan bir element olup oksijen ve silisyumdan sonra yer kabuğunda en çok bulunan elementtir (Barabasz ve ark., 2002). Alüminyum daha çok alaşım halinde otomotiv sanayinde, ambalajlama endüstrisinde, kapı pencere gibi inşaat konstrüksiyon malzemelerinde, mutfak aletleri ve elektronik ekipmanların korunmasında, su arıtımında flokülasyon maddesi olarak kullanılmaktadır (Wood ve ark., 2012).

Bu amaçla bu araştırmada, Al_2O_3' in mikro ve nano boyutlarının 10 mg/L derişimlerinin 7 günlük süreyle etkisinde *O.niloticus*' un solungaç, karaciğer ve kas dokularındaki metal birikim düzeyleri belirlenmiştir.

MATERYAL VE YÖNTEM

Araştırmada materyal olarak kullanılan *O.niloticus* türü balıklar Çukurova Üniversitesi Su Ürünleri Yetiştirme havuzlarından alınarak Çukurova Üniversitesi, Fen-Edebiyat Fakültesi, Biyoloji Bölümünde bulunan ve 12 saat aydınlık ve 12 saat karanlık fotoperyodu uygulanan kontrollü ortam şartlarına sahip Hayvan Ekofizyolojisi Laboratuvarına getirilmiştir. Laboratuvara getirilen balıklar 40x120x40 boyutlarındaki içerisinde 120 L su bulunan akvaryumlarda iki ay süreyle adaptasyon sürecine bırakılmışlardır. Adaptasyon ve deneyler süresince akvaryumlar içerisinde kullanılın suyun fiziksel ve kimyasal özellikleri Tablo 1 de verilmiştir.

Tablo 1. Deney suyunun fiziksel ve kimyasal özellikleri

Sıcaklık	22 ± 0.5 °C
pH	7.60 ± 0.40
Çözünmüş Oksijen	6.9 ± 0.35 mg/ L
Alkalinite	325 ± 0.40 mg/ L $CaCO_3$

Araştırmada Alüminyum oksitin iki farklı boyutu olan Al_2O_3' ün son derişimleri 10mg/L olacak şekilde mikro (45-75 µm, Nanografi) ve nano (<50 nm, Sigma Aldrich) boyutları kullanılmıştır. Partiküllerin karakterizasyonu Çukurova Üniversitesi Merkezi Araştırma Laboratuvarı'nda elektron mikroskobu (SEM) ve X-ışını kırınımı (XRD) analizleri ile gerçekleştirildi. Partiküllerin karakterizasyon metodu ve çözeltilerinin hazırlanması önceki çalışmamızda açıklanmıştır (Sezer Tuncsoy ve ark. 2019). Deneylerde belirlenen derişim dikkate alınarak her biri 40x120x40 cm boyutlarında olan 3 akvaryum kullanılmıştır. Her bir akvaryumun içerisine 9 adet balık konulmuştur. Deneyler üç tekrarlı olarak yürütülmüş, her tekrarda 3 balık kullanılarak toplamda 27 adet balık kullanılmıştır. Akvaryumların ilkine 120 L alüminyum içermeyen dinlenmiş çeşme suyu konarak kontrol grubu olarak değerlendirilmiş, diğer iki akvaryuma Al_2O_3' ün mikro ve nano boyutlarının belirlenen derişimdeki çözeltileri konmuştur. Deneyler süresince balıklar, günde bir kez toplam biyokütlenin % 2'si oranında hazır balık yemi (Pelet No:2) ile beslenmiştir.

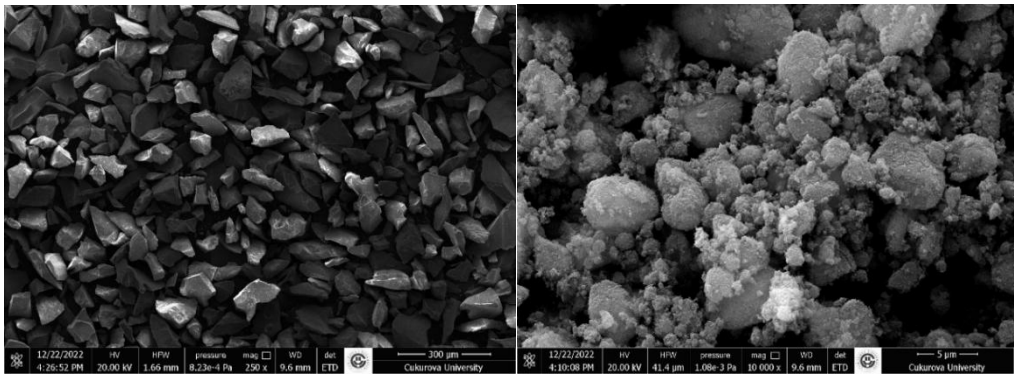
Deney süresince akvaryumlar içerisindeki deney çözeltileri her gün taze hazırlanmış ve stok çözeltiden uygun seyreltmeler yapılarak yenilenmiştir. 7 günlük etki süresi sonunda akvaryumlardan çıkartılan balıklar Etilen glikol mono fenil eter (Fenoksietanol, $C_8H_{10}O_2$; Merck) anestezik maddesi ile bayıltıldıktan sonra, çeşme suyu ile yıkanıp, kurutma kâğıdı ile

kurulanarak diseksiyona hazır hale getirilmiştir. Metal analizinde kullanılacak doku örnekleri, 105 ºC'de üç gün süre ile bekletilerek sabit tartıma hazır hale getirilerek ve kuru ağırlıkları belirlenmiştir. Deney tüplerine aktarılan doku örneklerinin üzerine 2 ml nitrik asit (HNO_3, % 65, Ö.A.: 1.40, Merck) ve 1 mL perklorik asit ($HClO_4$, % 60, Ö.A.:1.53, Merck) eklenerek (Muramoto, 1983) 120 ºC'de 8 saat süre ile yakılmıştır. Yakma işlemi tamamlandıktan sonra dokular polietilen tüplere aktarılmış ve ultra saf su ile 5 ml'ye tamamlanarak analize hazır hale getirilmiştir.

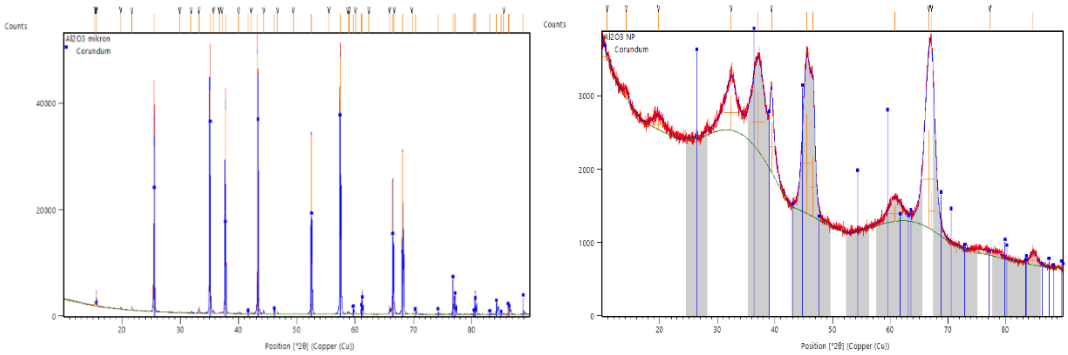
Dokulardaki alüminyum düzeyleri ICP-MS (Inductively Coupled Plasma Mass Spectrometry) ile ölçülmüştür. Verilerinin istatistiksel analizlerinde SPSS 21 paket programı kullanılarak Student Newman Keul's (SNK) testi uygulanmıştır.

BULGULAR VE TARTIŞMA

Al_2O_3' in mikro ve nanopartiküllerinin şekil, yüzey ve morfolojisinin karakterizasyonuna dair sonuçlar, Şekil 1 ve Şekil 2'de gösterilmektedir.



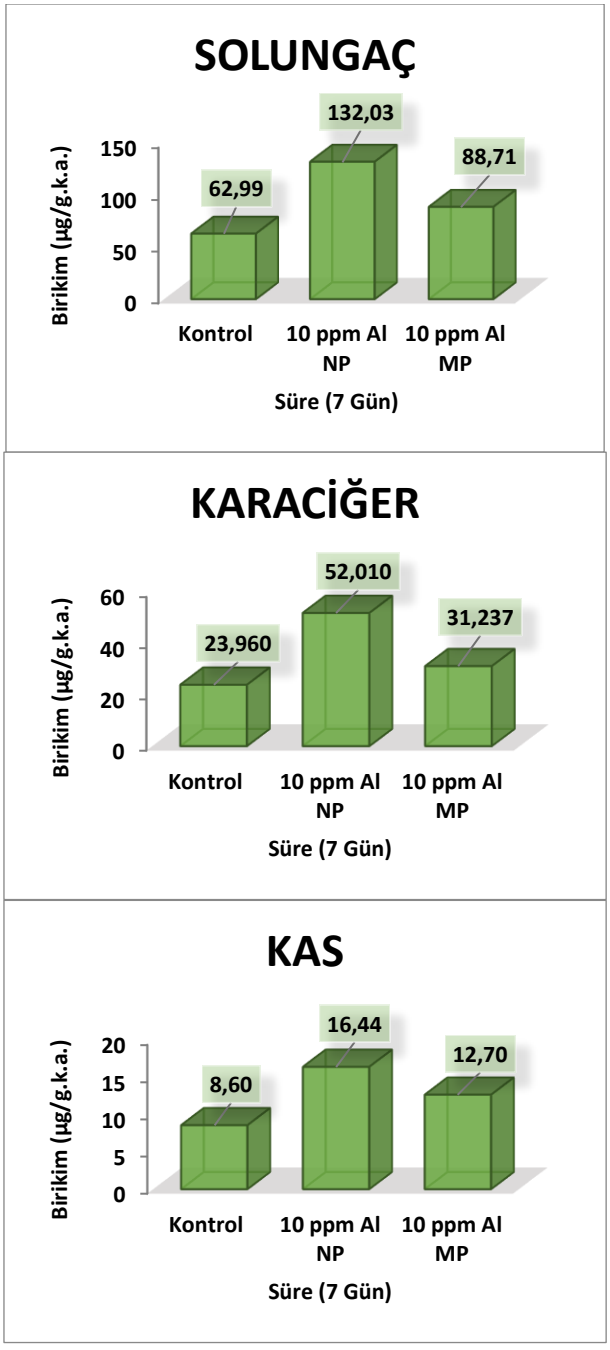
Şekil 1 Al_2O_3 MP and Al_2O_3 NP'nin taramalı elektron mikroskobu görüntüsü



Şekil 2 Al_2O_3 MP and Al_2O_3 NP'nin XRD analizi

Al_2O_3 NP'nin partikül boyut dağılımı 43.557 ± 6.443 nm; yoğunluğu 4.37 ± 0.0063 g/cm^3 ve Al_2O_3 MP'nin partikül boyut dağılımı 49.17 ± 6.655 µm; yoğunluğu 3.97 ± 0.0054 g/cm^3 olarak belirlenmiştir.

Balıklarda ağır metallerin mortalite üzerine etkileri metale ve metalin ortam derişimi ve etki süresine bağlı olarak değişim gösterir. Bu araştırmada incelenen tüm süre ve derişimlerde mortalite gözlenmemiştir. Mortailte gözlenmemesi, uygulanan derişimlerin belirlenen etki sürelerinde bu tür için letal olmaması ve metal etkisi sonucunda detoksifikasyon mekanizmalarının devreye girmesinden kaynaklanması ile açıklanabilir.



Şekil 3 Al_2O_3 MP and Al_2O_3 NP'nin dokularındaki metal birikimi

Al_2O_3' in her iki formunun etkisinde incelenen solungaç, karaciğer ve kas dokularında kontrole oranla önemli düzeyde artış olduğu gözlenmiştir (Şekil 3; $P<0.05$). Al_2O_3' in her iki formunun etkisinde dokular arasında 7 günlük etki süresi sonunda karaciğer>solungaç>kas şeklinde bir dizilim saptanmıştır. Yapılan bu araştırmada metal birikim düzeyi bakımından solungaç dokusunda yüksek çıkması, anılan dokunun kirleticilere direk maruz kalmasından, karaciğer dokusunda yüksek çıkması, bu dokunun balıklarda önemli detoksifikasyon organı olup, hem metabolizma hem de vücuttaki toksik maddelerin atılımında aktif olarak görev almasından kaynaklanabilir.

Abdel-Khalek ve ark. (2020) alüminyum oksit nanopartiküllerinin *O. niloticus*'da karaciğer, solungaç, böbrek, deri ve kas dokusunda önemli düzeyde birikim gösterdiğini belirtmiştir. Murali ve ark. (2018) Al_2O_3 NP etkisine bırakılan *O. mossambicus*'ta

solungaçlarda birçok histolojik hasar gözlendiği bildirmiştir. *B. rerio*'da Al'ni etkisinde karaciğer, solungaç ve kas dokularında birikim gösterdiği belirtilmiştir (Anandhan ve Hemalatha, 2009).

Sonuç olarak yapılan bu çalışmada Al NP ve Al MP'nin *O. niloticus*'un dokularındaki birikim düzeyleri üzerine etkileri karşılaştırılmalı olarak incelenmiş, bunun sonucunda Al NP'nin doku birikimi bağlamında Al MP'ye oranla daha toksik olduğu saptanmıştır. Metaller arasındaki bu farklılık Al NP'nin boyutlarının küçük, yüzey alanlarının geniş olması; boyutlarının küçük olması nedeniyle kolaylıkla hücre membranlarını geçerek sitotoksisiteye neden olması ve daha fazla ROS oluşturması ile açıklanabilir. Bununla birlikte incelenen metallerin etkisinde her iki uygulamada da anılan türde değişikliklere neden olması bu parametrelerin kirlilik belirteci olarak kullanılabileceği sonucuna varılmıştır.

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PROTEIN ISOLATION FROM *Ulva* SPECIES: COMPARISON OF EXTRACTION METHODS

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ABSTRACT
With the increase in the world population, the need for sustainable protein sources is increasing day by day. *Ulva* species stand out as an alternative protein source due to their high protein content and essential amino acid profile. However, protein extraction from *Ulva* is a challenging process due to the presence of polysaccharides in the cell walls and the complexation of phenolic compounds with proteins. In this study, different extraction methods used to extract protein from *Ulva* were compared. Alkaline extraction, one of the most widely used methods in literature, provides high yields by increasing protein solubility. However, the use of high pH levels can negatively affect the functional and nutritional properties of proteins. Enzymatic extraction is a method that targets cell walls and releases proteins, but it is costly and requires optimization on a species basis. Pulsed electric field (PEF) combined with mechanical pressure offers advantages in terms of low energy consumption but provides lower protein yields compared to other methods. High-speed homogenization (HSH) stands out as the method that efficiently disrupts cell walls using mechanical forces and, when combined with alkaline extraction, provides the highest protein yield (up to 60%). Ultrasonic extraction has been generally used for polysaccharides, whereas its use for protein extraction is limited, and more research is needed on this topic. In conclusion, the optimal method to extract protein from *Ulva* depends on the targeted protein purity, economic viability and environmental sustainability. The combination of techniques such as ultrasound, PEF and HSH shows promise in terms of optimum yield and protein quality. Future research should focus on optimizing the impact of these methods on protein yield and functional properties.
Keywords: Seaweed, *Ulva* spp., Protein extraction, *Ulva* protein

INTRODUCTION

Seaweeds are organisms that colonize aquatic habitats and are known for their potential health benefits in the pharmaceutical, agricultural, food, and animal feed industries (Kim & Wijesekara, 2010; Mohamed et al., 2012; Kim, 2014; Buckley et al., 2023). As a rich source of calcium (Ca), potassium (K), and sodium (Na), the high mineral content of seaweeds stems from their ability to absorb inorganic substances from the surrounding environment (Morais et al., 2020). Although the composition of seaweeds varies depending on external factors such as species, ambient temperature, and light intensity, they are rich sources of bioactive compounds, including various phlorotannins, sterols, sulfated polysaccharides, peptides, and proteins (Wijesekara et al., 2010; Li et al., 2011; Mišurcová, 2011; Stévant et al., 2017). Due to their ability to provide numerous ecosystem services and their bioremediation potential, seaweeds are considered a promising and sustainable resource (Juul et al., 2021; Bleakley & Hayes, 2017). The bioremediation properties of seaweeds contribute to improving water quality by facilitating nutrient removal and carbon sequestration in their cultivation areas (Neveux et al., 2018). Seaweeds are seen as a sustainable source of protein that can support the fight against climate change and meet the necessary agricultural expansion by not competing with existing land crops (Stedt et al., 2022; Spillias et al., 2023).

The rapid increase of the world population is increasing the demand for sustainable and alternative protein sources (Godfray et al., 2010; Henchion et al., 2017). A study conducted by Polat et al. (2023) confirmed that the protein content of seaweeds is comparable to that of soybeans and eggs. Due to their rich nutritional composition and environmental benefits, seaweeds stand out as one of the potential resources that could meet this growing demand. The environmental benefits of seaweeds include their ability to provide various ecosystem services such as nutrient recycling and carbon sequestration. These capabilities position seaweeds as a viable alternative to land-based protein sources (Seghetta et al., 2016; Duarte et al., 2017; Elizondo-González et al., 2018; Neveux et al., 2018; Zhang & Thomsen, 2019).

Seaweeds are classified into three groups: brown algae (*Phaeophyceae*), red algae (*Rhodophyceae*), and green algae (*Chlorophyceae*). Green algae, which can exist in both unicellular and multicellular forms, are particularly rich in bioactive compounds with various functional properties. Compared to brown and red algae, green algae have a higher carbohydrate content, with their primary polysaccharide being *Ulva*n (Subbiah et al., 2023). The green algal genus *Ulva*, commonly known as sea lettuce, is a biologically significant material with great potential for protein extraction. This is due to the high essential amino acid (EAA) content of the *Ulva* genus, which constitutes approximately 36–42% of the total amino acids (Fleurence et al., 2018; Magdugo et al., 2020).

Protein content of *Ulva*

Ulva, with a protein content of ranges between 10% and 27% on a dry matter basis, has similar or higher protein content than some commonly consumed vegetables (Fleurence et al., 2018). Especially in dry matter-based comparisons, the protein content of *Ulva* can significantly exceed that of vegetables such as spinach and peas. The protein content of *Ulva* varies depending on geographical location, season, and environmental factors (Yu-Qing et al., 2016; Cindana Mo'o et al., 2020). For instance, *Ulva* species cultivated in nitrogen-rich waters can exhibit protein contents exceeding 30% on a dry matter basis. However, *Ulva* species naturally grown in Danish waters have been reported to contain only 8% protein on a dry matter basis (Naidoo et al., 2006; Juul et al., 2022). These findings indicate that environmental factors and cultivation conditions significantly influence the protein content of *Ulva* species. *Ulva* exhibits varying protein contents among its species due to factors such as genetic differences, environmental conditions, and nutrient availability (Table 1). While the protein content of *Ulva reticulata* and *U. prolifera* is generally around 20%, *U. lactuca* can contain up to 32% protein

on a dry weight basis, depending on environmental conditions (Ratana-arporn & Chirapart, 2006; Pirian et al., 2016; Malo, 2017). This characteristic allows *U. lactuca* to serve as a partial alternative to traditional protein sources such as soybean flour (Ribeiro et al., 2023). Additionally, significant seasonal variations in protein content have been observed in *Ulva* species. For example, *U. lactuca* exhibits its lowest protein content (8.7% on a dry weight basis) in April, while reaching its highest protein content (32.7%) in August (Fleurence et al., 2018).

Table 1. Protein contents of *Ulva* species (Fleurence et al., 2018; Subbiah et al., 2023).

Species	Protein content (% of dry weight)
U. lactuca	8,2-32,7
U. pertusa	17,5-26
U. rigida	6,64
U. clathrata	11,5
U. compressa	12,27

The high protein content of *Ulva* species makes them a suitable alternative for consumers with protein requirements. By providing a sustainable and renewable protein source, seaweeds contribute to reducing environmental impacts compared to traditional protein sources. This makes seaweeds an attractive alternative for the agricultural and food industries. *Ulva* species in particular can be used as a sustainable source of protein production in seaweed growing regions. In order for *Ulva* species to be used as a protein source, the amino acid composition should be nutritionally appropriate as well as the high protein content (Juul et al., 2024). A nutritionally appropriate amino acid composition means that these amino acids should contain the EAAs required by the human body in sufficient amounts and in the correct ratios. *Ulva* species generally contain EAAs comprising approximately 30–45% of the total amino acids (TAA) (Machado et al., 2020; Samarasinghe et al., 2021). In addition, protein extraction plays a important role in utilizing *Ulva* as a protein source. Protein extraction increases the EAA content and the digestibility of proteins (Juul et al., 2022). Studies have reported that protein extraction from *Ulva* yields a high EAA content, ranging from 40.4% to 45.5% (Table 2) (Trigo et al., 2021; Juul et al., 2022). The quality of the extracted protein is directly influenced by the pre-treatments and extraction methods applied to *Ulva*. Therefore, to effectively utilize *Ulva* as a protein source, it must be processed under appropriate conditions and with suitable techniques.

Table 2. Amino acid (AA) composition and essential amino acid (EAA) content as percentage of total amino acid (TAA) of different *Ulva* species (Bikker et al., 2016; Harrysson et al., 2018; Trigo et al., 2021)

Amino acids (% of TAA)	*U. lactuca*[a]	Extract	*U. lactuca*[b]	Extract	*U. fenestrata*[b]	Extract
Alanine	7.8	8.2	8.4 ± 0.2	6.7 ± 0.0	7.7 ± 0.7	5.3 ± 0.0
Histidine	1.0	1.1	0.3 ± 0.1	2.2 ± 0.0	3.0 ± 0.1	4.2 ± 0.0
Isoleucine	4.0	4.6	4.3 ± 0.1	4.9 ± 0.1	4.1 ± 0.3	4.5 ± 0.0
Leucine	7.4	8.6	7.2 ± 0.1	7.4 ± 0.1	7.7 ± 0.6	7.8 ± 0.0
Phenylalanine	5.4	6.4	4.9 ± 0.1	5.2 ± 0.1	5.3 ± 0.3	5.3 ± 0.0
Threonine	4.7	5.9	5.2 ± 0.1	5.0 ± 0.1	5.6 ± 0.5	5.7 ± 0.0
TAA (g/100 g DM)	26.3	40.1	19.6 ± 0.6	51.2 ± 2.1	12.7	56.6
EAA (% of total AA	40.5	45.5	38.7	42.3	37.6	40.7
True protein (g/100 g DM)[c]	22.6	34.6	16.9	44.1	11.0	48.8

[a]Wild harvest, Irish coast
[b]Sweden, cultivated
[c]True protein is calculated as TAA x 100/1

PROTEIN EXTRACTION FROM *Ulva*

The protein structure of seaweeds different from that of other plants, such as legumes. The storage proteins of legumes such as soybeans are free and accessible in the cells. Storage proteins can be more easily separated from plant tissue, making plant extraction easier (Tenorio et al., 2018). However, in seaweeds, proteins are usually localized in pyrenoids. Pyrenoids are structures within chloroplasts that contain molecules associated with photosynthesis. Unlike the storage proteins in legumes, the proteins stored in pyrenoids are not directly utilized as an energy source. Instead, the proteins serve structural or enzymatic functions. These types of proteins maintain the structure of the cell and are involved in metabolic processes. Additionally, excess nitrogen in seaweeds is stored as free amino acids rather than being directly incorporated into proteins (Angell et al., 2014). These free amino acids, which are not directly part of the protein structure, complicate the release and isolation of proteins from seaweed biomass. Consequently, the accessibility of proteins in seaweeds is lower, making protein extraction more complex and less efficient.

The selection of the method for protein extraction from seaweeds is influenced by the chemical composition of the seaweed species (Juul et al., 2024). The high fiber content and ash levels present in seaweeds contribute to the formation of high viscosity, which complicates the protein extraction process (Joubert & Fleurence, 2008; Sari et al., 2015). In addition, phenolic compounds can form complexes with proteins and prevent protein extraction (Juul et al., 2021). For these reasons, it is essential to obtain appropriate extraction methods to obtain efficient extracts from seaweeds.

There are two main approaches for obtaining protein from *Ulva* species: direct protein extraction and the removal of other components. In the direct protein extraction method, proteins within the biomass are specifically targeted and directly isolated. Proteins are solubilized using various extraction techniques and separated from the biomass (Harrysson et al., 2018; Kazir et al., 2019). In the removal of other components method, it is aimed to concentrate proteins. In this method, protein is not extracted directly. Instead, other components in the biomass such as lipids and ash are removed, leaving a fraction with a higher protein content (Gajaria et al., 2017; Magnusson et al., 2019).

Extraction methods used in protein extraction of *Ulva*

Alkaline extraction method: Alkaline extraction method is a method that provides high efficiency in protein extraction from *Ulva* (Wong & Cheung, 2001). However, some chemicals used in this extraction method are not suitable for food production. For instance, in the alkaline extraction method, 36% of the total protein can be obtained when the protein is dissolved using 2-mercaptoethanol and then precipitated with ammonium sulfate. Although 2-mercaptoethanol is effective in protein solubilization, the proteins obtained by this method are not used for food applications. The use of detergent-like surfactants can further increase protein yield compared to alkaline extraction. However, such substances are also unsuitable for food production (Trigo, 2023). In summary, although there are methods that increase protein yield, appropriate solutions need to be developed for food production.

In a study conducted by Harrysson et al. (2019), the application, yield, and potential disadvantages of the pH-shift method, which is suitable for food applications, were investigated. For this purpose, the pH-shift method, incorporating high-speed homogenization (HSH) and alkaline extraction, was used to extract protein from dried and ground *Ulva*. HSH was applied to facilitate the solubilization of proteins by disrupting cell structure. Subsequently, during the alkaline extraction stage, two successive incubations at pH 8.5 and pH 12 were performed to increase protein solubility. The solubilized proteins were then purified using the isoelectric precipitation method. This method achieved a total protein yield of 29%. However, the use of high pH in the pH-shift method can lead to undesirable chemical

changes. Especially when this method is combined with high temperatures, cross-linking in proteins and amino acid racemization (the conversion of L-isomers to D-isomers) may occur in proteins. Similar observations have been reported in other biomasses such as soybeans and alfalfa. As a result, HSH increases the extraction efficiency by facilitating cell disruption. Although alkaline extraction improves protein solubility, exposure to high pH can lead to undesirable chemical changes that disrupt the structure of proteins. Therefore, further optimization is required to improve the functional and nutritional properties of proteins obtained by pH-shift method (Juul et al., 2021).

Another study by Harrysson et al. (2018) compared different methods for protein extraction from *Ulva* and showed that the pH-shift method provides a higher protein concentration. One of the compared methods involved protein solubilization by ultrasonic extraction followed by ammonium sulfate precipitation and the other was accelerated solvent extraction with 50% methanol. However, both methods resulted in a lower protein concentration than that of raw biomass. In contrast, the pH-shift method yielded a significantly higher protein concentration, making it a more efficient alternative. In this study, it was reported that during pH-shift extraction, maximum protein solubility occurred at pH 12, whereas the highest precipitation efficiency was observed at pH 2. A similar method was applied by Juul et al. (2021), but with a lower yield (6.8%). This difference is believed to be due to variations in biomass and preprocessing techniques.

The study conducted by Juul et al. (2022) focused on how protein extraction from *U. fenestrata* can be performed and how the protein yield obtained through this process can be increased. For the protein extracted from *Ulva* to be used efficiently in the food or feed industry, it is essential to first remove the high fiber, and phenolic compounds present in the seaweed. These compounds hinder protein digestibility, making their removal necessary for effective utilization. In this study, different approaches were evaluated, including mechanical pressing, alkaline extraction, and a combination of both methods, with the aim of improving protein yield. The results showed that the protein yield obtained by mechanical pressing alone was relatively low ($5.0\% \pm 0.2$). When alkaline extraction was used, the protein yield increased to $6.8\% \pm 0.2$. Alkaline extraction proved to be a more effective method, solubilizing a greater proportion of proteins compared to mechanical pressing. However, when a combination of both mechanical pressing and alkaline extraction was applied, the protein yield significantly increased to $23.9\% \pm 0.3$. This outcome demonstrated that the combined method was much more efficient than either method used individually. In conclusion, the combination of mechanical pressing and alkaline extraction allows for higher protein extraction yields by integrating the advantages of both techniques.

In the alkaline extraction method, various techniques such as isoelectric precipitation, heat precipitation, and filtration from the supernatant can be used to increase protein concentration (Juel et al., 2024). In a study conducted by Kazir et al. (2019), proteins were purified using filtration (0.45 μm filter) and dialysis (2 kDa, against ultrapure water) following alkaline extraction performed in an ultrasonic water bath. As a result, a total protein yield of *10–11%* was achieved.

The alkaline extraction method is one of the most used techniques for *Ulva* protein extraction. In addition to alkaline extraction, mechanical pre-treatments and various purification techniques can be applied to enhance protein extraction yield. However, the characteristics of biomass and pre-extraction treatments have a significant impact on protein yield.

Enzymatic extraction method: The efficiency of protein extraction from seaweeds is limited due to the presence of cell wall mucilage containing anionic or neutral polysaccharides. Enzymes that degrade fibers can be used to break down the cell walls of seawees, thereby

increasing protein accessibility. Since fiber composition varies among *Ulva* species, the selection of enzymes for enzymatic extraction must be optimized for each species (Echave et al., 2021).

In a study conducted by Hardouin et al. (2016), an enzyme-assisted extraction method was used to obtain bioactive extracts from *U. armoricana*. The researchers aimed to break down the cell walls of *U. armoricana* and release proteins, sugars, and organic compounds using six different commercial enzymes. Endo-proteases were tested for protein degradation, along with enzymes that degrade polysaccharides. It was observed that endo-proteases facilitated the release of intracellular proteins more effectively and increased solubility by breaking down polysaccharides. The amount of protein obtained after enzyme-assisted extraction was found to be 1.75 times higher compared to the amount obtained using conventional methods. This finding suggests that enzymes enhance the extraction efficiency by breaking down the cell wall and releasing intracellular components more effectively. In conclusion, enzyme-assisted extraction enabled the recovery of proteins, sugars, and organic compounds from *U. armoricana* with higher efficiency. Additionally, the extracts obtained through enzyme-assisted extraction exhibited antiviral and antioxidant properties.

In a study conducted by Malvis Romero et al. (2023), the extraction of *Ulva*n, a polysaccharide from *U. fenestrata*, was performed. The study investigated the effects of commercial enzymes such as cellulase and protease on cell wall degradation. These enzymes break down the cellulose and protein structures in the seaweed cell wall, facilitating the release of water-soluble compounds. The addition of proteases during enzymatic extraction aids in the release of cell wall proteins, potentially increasing protein yield. During *Ulva*n extraction, the enzymes contributed to the solubilization of proteins, leading to the release of a higher amount of protein. The fact that proteins became water-soluble during extraction indicates an improvement in protein yield.

In a study conducted by Postma et al. (2018), protein extraction from *U. lactuca* was performed using a polysaccharidase mixture, particularly cellulase and other polysaccharidases, achieving a protein yield of 26.1%. This provides strong evidence that the polysaccharidase mixture effectively degrades the cell walls, thereby enabling higher protein extraction efficiency. This method represents a significant step by utilizing seaweeds as a high-yield protein source.

In a study by Steinbruch et al. (2023), it was highlighted that the combined use of cellulase and pulsed electric field (PEF) in *Ulva* protein extraction doubled the protein yield compared to using either method alone. The addition of cellulase facilitates the breakdown of cell walls, making biomolecules more accessible. Meanwhile, PEF temporarily increases cell membrane permeability, aiding the release of water-soluble proteins. When these two processes are combined, a higher protein yield is achieved. These findings highlight a research area aimed at improving existing protein extraction methods from seaweed, offering more efficient extraction techniques on an industrial scale.

In enzyme-assisted extraction, a balance must be established between enzyme quantity and extraction yield. The key point here is that enzyme and substrate ratios should be carefully adjusted to be suitable for industrial-scale applications. Otherwise, excessive enzyme usage can increase costs and reduce efficiency in industrial applications. Therefore, optimal enzyme utilization is recommended for enzyme-assisted extraction.

Ultrasonic extraction: Pan-Utai et al. (2022) conducted a study aiming to extract proteins from *U. rigida* using an ultrasound-assisted extraction method. Ultrasonic waves were utilized to disrupt the cell walls of *U. rigida*, facilitating the release of proteins. The ultrasound-assisted extraction method was found to provide a higher protein yield compared to conventional methods, and the extracted proteins exhibited significant antioxidant properties.

This study suggests that proteins obtained from *U. rigida* could serve as a potential resource in the food and health sectors, and that ultrasound-assisted extraction is an effective method for this process.

Recent studies have highlighted the effectiveness of ultrasonic-assisted extraction for the extraction of carbohydrates from *Ulva* species. However, there is limited research on the use of ultrasonic extraction for protein extraction from *Ulva* and other seaweeds. Ultrasonic extraction is commonly used for the extraction of biologically active compounds, particularly polysaccharides and phenolic compounds, primarily because ultrasonic waves effectively break down cell walls, increasing accessibility to internal compounds. However, studies on protein extraction from *Ulva* are limited, with most research focusing on carbohydrates or lipids. The effect of ultrasonic extraction on proteins can be a more complex process, particularly due to the structural properties of proteins and their location within the cell walls. Extracting proteins is a more challenging process compared to polysaccharides, as proteins in seaweeds may be bound to the cell wall, making their release more difficult. In this context, optimizing ultrasonic extraction methods to increase protein extraction efficiency from *Ulva* species is necessary. For ultrasonic extraction to be used as a potential method in this field, it is essential to determine the optimal parameters and investigate how the structural properties of proteins are affected. By doing so, high-yield protein extraction from seaweeds can be achieved, making these proteins valuable compounds for use in various sectors, such as the food industry.

Table 3. Protein extraction methods and protein yields of different *Ulva* species (Fleurence et al., 1995; Harrysson et al., 2018; Harrysson et al., 2019).

Species	Extraction method	Protein yield (% of biomass protein)
Acidic extraction		
U. rotundata	Acidic extraction	13.8 ± 1.2
U. rotundata	Acidic extraction with sonication	16.1 ± 0.9
U. rotundata	Acidic extraction followed by alkaline extraction	25.2 ± 1.9
U. rigida	Acidic extraction	9.4 ± 1.6
U. rigida	Acidic extraction with sonication	10.4 ± 0.8
U. rigida	Acidic extraction followed by alkaline extraction	17.5 ± 1.3
Pulsed electric field (PEF)		
U. lactuca	PEF	15.1 ± 0.7
U. ohnoi	PEF and mechanical press, filtration, alkaline extraction	14.9
Enzyme-assisted extraction		
U. rigida	Extraction with cellulases	<1.0
U. rigida	Extraction with mixture of polysaccharidases	18.5 ± 2.1
U. rotundata	Extraction with cellulases	<1.0
U. rotundata	Extraction with mixture of polysaccharidases	22.0 ± 1.5
High-speed homogenization (HSH)		
U. lactuca	HSH, osmotic shock, alkaline extraction, acid precipitation	13.7 ± 0.2
U. fenestrata	HSH, osmotic shock, alkaline extraction, acid precipitation	29.0

CONCLUSION AND DISCUSSION

This study investigates and compares the extraction methods used to obtain proteins from *Ulva* species. Various extraction methods are employed in the process of protein

extraction from *Ulva* species. Commonly used methods in the literature include alkaline extraction, ultrasound-assisted extraction, high-speed homogenization (HSH), osmotic shock, enzymatic hydrolysis, and a combination of pulsed electric fields (PEF) with mechanical pressure. Alkaline extraction stands out as a method that provides high yield by increasing the solubility of proteins. When used with HSH, protein yields have been shown to reach up to 60% (Harrysson et al., 2018; Harrysson et al., 2019). However, the disadvantages of this method include protein denaturation and the loss of some functional properties.

High-speed homogenization (HSH) is a method that effectively breaks down cell walls using mechanical forces. It has been determined that this method provides higher protein yield compared to other traditional methods, but its energy consumption is significantly high (Postma et al., 2018). The combination of pulsed electric fields (PEF) and mechanical pressure weakens the cell wall, facilitating the release of proteins. However, the protein yield remains lower compared to HSH (%14.9–15.1). Despite this, the PEF method stands out as one of the most energy-efficient methods. In terms of the sustainability of industrial-scale applications, PEF is considered advantageous due to its low energy requirements.

Enzymatic extraction is a method that facilitates the release of proteins by selectively targeting specific cell components through enzyme interactions. However, the high cost of enzymes and the challenges of process optimization limit the widespread applicability of this method. Ultrasonic-assisted extraction, although commonly used for carbohydrate extraction, has seen limited use for protein extraction. Ultrasonic energy facilitates the disruption of cell walls, thereby increasing the protein extraction yield. Some studies have shown that probe-type ultrasonic devices provide high efficiency. However, issues with repeatability and the potential negative effects of direct exposure of samples to ultrasonic waves on protein structure have been noted. Therefore, further research is needed on lower energy density and more controlled approaches, such as ultrasonic bath systems.

A review of the current literature reveals that most of the methods used for protein extraction from *Ulva* species are primarily focused on carbohydrate extraction. The potential of ultrasonic-assisted extraction for protein extraction has not been fully explored. While existing studies generally indicate that a combination of alkaline extraction and HSH provides the highest protein yield, the effectiveness of innovative and environmentally friendly techniques, such as ultrasonic extraction, in protein isolation needs to be investigated in more detail.

In conclusion, the most suitable method for protein extraction from *Ulva* species depends on the targeted protein purity, industrial applicability, and energy consumption. A combination of ultrasonic-assisted extraction, PEF, and HSH methods offer promising approaches in terms of optimal yield and environmental sustainability. Future studies should thoroughly investigate the combinations of these methods and how they affect the functional properties of the proteins.

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QUANTUM-LIKE ENCRYPTION SUPPORTED BY RANDOMNESS BASED ON FIBONACCI AND KAKUTANI

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Abstract
In this study, an innovative and robust encryption algorithm is designed by combining random number generation, Fibonacci sequences, and a generalized form of the Collatz conjecture. The core of the algorithm involves assigning a number from the Fibonacci sequence to each letter in the alphabet and applying randomness-based iterative transformations to these numbers. In the first step, random numbers are generated using Python (with secret inputs), and values obtained from the Fibonacci sequence are assigned to each letter sequentially. The critical point here is using *secret* instead of *random* to generate numbers, minimizing the risk of the SEED being compromised in random generation. Each letter undergoes an iterative transformation process with a unique random number (k). During the transformation: if the number is odd, $3n + k$ is applied; if even, $n/2$ is used. Here, n denotes the Fibonacci term F_n. The transformation ends when the value is reduced to 1. The encryption is completed by assigning the total number of steps recorded during this process as the new representative of the letter. This algorithm, by combining randomness and mathematical sequences, provides a highly secure encryption system that is hard to decipher and offers a strong structural security. The randomness ensures that only the algorithm's designer can decrypt the message, while the orderliness of the Fibonacci sequence and the complexity of the transformation rules reinforce the theoretical strength of the algorithm. Ultimately, each letter is represented by the total number of steps recorded during the iteration. This method serves the purpose of designing an encryption algorithm resistant to potential threats from QUANTUM computers. The innovative combination of random numbers and mathematical transformations establishes a unique security system that can only be solved by the one performing the encryption. This algorithm contributes to both theoretical mathematics and modern cryptography, offering not only a strong security layer but also an inspiring approach for developing new encryption techniques.
Keywords: Kakutani conjecture, Quantum encryption, Fibonacci sequence, Cryptography and data security, Python algorithm.

2. Method

In this study, an encryption algorithm combining random number generation, Fibonacci sequences, and generalized Collatz (KAKUTANI conjecture) transformations was designed and implemented. The design and implementation steps of the algorithm are structured as follows:

1. **Random Number Generation:** A random number k was generated for each letter using the Python programming language (via import secrets). Python's built-in secrets module was utilized to ensure randomness. This unpredictability at the beginning of the algorithm adds uncertainty to the encryption. Furthermore, the absence of a 'seed' in the secrets module strengthens the resistance against attacks, bringing the encryption system a step closer to quantum-level security.
2. **Encoding with the Fibonacci Sequence:** Before starting the encryption process, each letter in the alphabet was assigned a numerical value derived from the Fibonacci sequence. For instance, $A = F_1, B = F_2, C = F_3$, and so on. Here, $F_i \; for \; i = 1, 2, 3, \ldots, 29$ are Fibonacci numbers. The mathematical structure of the Fibonacci sequence forms the foundational values of the letters.
3. **Generalized Collatz Transformations (Kakutani Conjecture):** Using the Fibonacci value of each letter and the generated random number k, an iterative transformation process was initiated for each letter. This transformation follows the rules:

- If the value is odd $\rightarrow 3n + k$
- If the value is even $\rightarrow n / 2$

This process ends when the value is reduced to 1 for each letter.

4. **Encryption Criteria:** The encrypted value for each letter is defined either as the total number of steps taken during the iteration process or the maximum value reached during the transformation. The selection between these two criteria depends on the intended application of the algorithm.
5. **Python Implementation:** All steps of the algorithm were coded and tested in Python. Thanks to Python's ease of use and its extensive mathematical libraries, both the random number generation and the iterative transformations were implemented efficiently.

This method presents an innovative encryption algorithm with a solid mathematical and practical foundation. The combination of randomness, mathematical structure, and iterative processes used in the encryption design provides a reliable and potentially quantum-resilient encryption system.

3. Findings

This study aims to develop an innovative encryption algorithm by combining random number generation, Fibonacci sequences, and a generalized form of the Collatz conjecture. The proposed algorithm integrates both randomness and mathematical regularity principles to offer a strong security infrastructure.

At the core of the algorithm lies the assignment of each letter in the alphabet to a numerical value derived from the Fibonacci sequence, followed by randomness-based iterative transformations applied to these values. Unlike classical methods, random number generation in this system is implemented using Python's secrets module, which minimizes the risk of SEED exposure. This results in a more secure structure compared to traditional random number generation techniques.

The encryption process is based on transformation rules that are initiated with a unique random number assigned to each letter. Depending on whether the Fibonacci-based value is odd or even, different rules are applied. The iterative process continues until the value is reduced to 1, and the encrypted representation of the letter is determined by either the total number of steps or the maximum value reached during the process.

In our study, each letter of the Turkish alphabet is sequentially mapped to a corresponding term in the Fibonacci sequence $(e.g., 2, 3, 5, 8, 13, 21, 34, \dots)$. By the definition of the Fibonacci sequence, each term is the sum of the two preceding ones. Any symbols or characters following the last letter (if needed) are assigned Fibonacci numbers that follow the last letter's value. Finally, the space between words is also assigned a Fibonacci number, ensuring that every component—including spaces—has a numerical representation (see Table 1).

The numerical representations of letters are then transformed based on the generalized Collatz conjecture. If a number is even, it is halved; if it is odd, it is transformed via the expression $3n + k$, where k is a random number generated using the Python secrets module. After the initial transformation, the process follows the standard Collatz rules (see Table 2).

Let's now examine these stages in more detail:

In Python, standard methods for random number generation—especially the random module—typically require a starting value (seed). When the same seed is used, the same sequence of random numbers is produced, making the process predictable. However, this predictability poses a serious security risk in high-security applications like cryptography, where such predictability can facilitate attacks.

To overcome this vulnerability and achieve stronger security, cryptographically secure random number generators must be used. For this purpose, Python provides the secrets module, which ensures a higher entropy level and significantly reduces the predictability of the generated values. Thus, it not only offers a safer alternative to traditional methods, but also serves as a reliable tool for high-security applications like quantum encryption.

A Comparison Between Seed and Secrets from the Perspective of Encryption Reliability:

Advantages of the secrets Module:

- **No Need for a Seed:** The secrets module does not require a seed, eliminating the predictability of the generated values and ensuring a more secure structure.
- **Cryptographic Strength:** Random numbers produced by secrets rely on unpredictability and are therefore more resistant to cryptographic attacks. Unlike standard methods, it complies with high-security standards for randomness.
- **Quantum Encryption Compatibility:** Advanced encryption algorithms, including quantum encryption, rely heavily on the reliability of random number generation. The high entropy and reliable randomness provided by secrets make it a solid foundation for such applications.

Therefore, using the secrets module for random number generation significantly enhances the security of the encryption algorithm and meets modern cryptographic requirements.

Comparison of random and secrets Modules:

- **random Module:**
  - Fast and easy to use.
  - Ideal for simulations, games, or applications where security is not critical.
  - Not suitable for secure applications as the random numbers it generates can be predicted and are vulnerable to attacks.
- **secrets Module:**
  - Meets high-security requirements.
  - Generates unpredictable random numbers that are resistant to cryptographic attacks.
  - Designed for the secure generation of encryption keys, passwords, and other sensitive data.
  - Due to its high entropy, it offers stronger randomness against quantum computer threats.

Below are sample Python codes for generating random numbers using both random and secrets modules. If a broader range is required with the secrets module, appropriate algorithms for range adjustment are also provided.

Key Notes:

1. The random module is used for generating random numbers in Python.
2. The random.randint(min, max) function generates a random integer within the specified range.
3. User input determines how many numbers to generate and their minimum and maximum values.
4. The generated numbers are displayed as a list.
5. $b - a + 1$: Determines the range width.
6. $+ a$: Ensures that numbers start from a, not from 0.
7. count: Specifies the number of random values to be generated.

Examples:

- To generate numbers between $0\ and\ 1000$: random_in_range $(0, 1000, 29)$
- For a negative range $(e.g., -50\ to\ 50)$: random_in_range $(-50, 50, 29)$

This flexibility allows users to adjust the range and generate random numbers suited to their specific needs.

```
+ Kod  + Metin

import random

# Rastgele sayı üretmek için bir fonksiyon
def rastgele_sayilar_uret(adet, min_deger, max_deger):
    return [random.randint(min_deger, max_deger) for _ in range(adet)]

# Kullanıcıdan giriş alma
adet = int(input("Kaç adet rastgele sayı üretmek istiyorsunuz? "))
min_deger = int(input("Rastgele sayılar için minimum değer: "))
max_deger = int(input("Rastgele sayılar için maksimum değer: "))

# Rastgele sayıları üret ve ekrana yazdır
rastgele_sayilar = rastgele_sayilar_uret(adet, min_deger, max_deger)
print(f"Üretilen rastgele sayılar: {rastgele_sayilar}")

Kaç adet rastgele sayı üretmek istiyorsunuz? 29
Rastgele sayılar için minimum değer: 1
Rastgele sayılar için maksimum değer: 29
Üretilen rastgele sayılar: [3, 24, 23, 22, 9, 23, 25, 12, 14, 12, 12, 27, 29, 11, 21, 7, 24, 10, 22, 23, 28, 15, 24, 24, 15, 16, 3, 25, 13]
```

Fig 1. Random numbers generated with the Random module

```
import secrets

# 29 tane rastgele sayı üretmek için bir liste oluştur
random_numbers = [secrets.randbelow(100) for _ in range(29)]

# Rastgele sayıları yazdır
print("29 Rastgele Sayı:", random_numbers)

29 Rastgele Sayı: [56, 12, 79, 80, 35, 31, 23, 38, 27, 52, 31, 36, 50, 41, 11, 99, 26, 67, 18, 78, 36, 94, 72, 89, 17, 52, 67, 10, 2]
```

Fig 2. Random numbers generated with the Secrets module

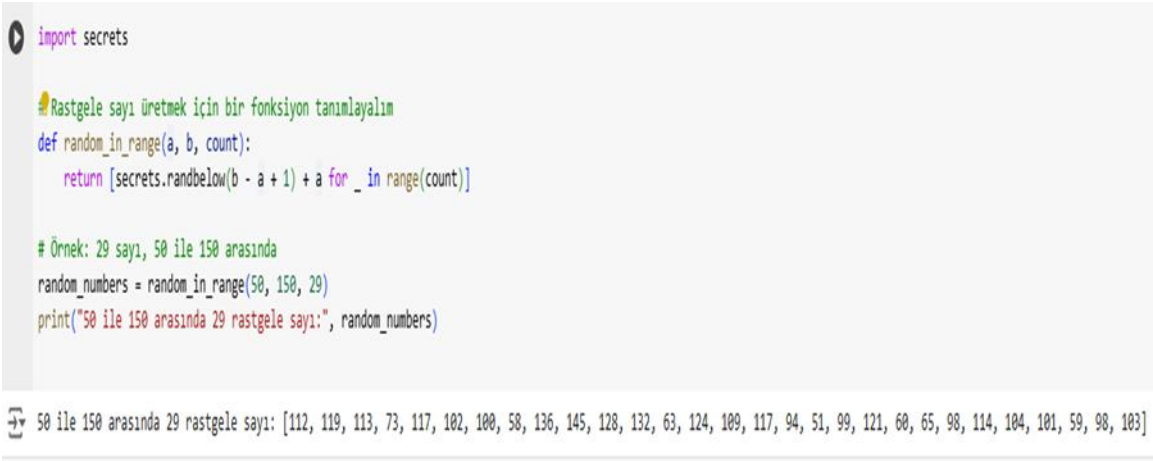

Fig 3. Generating numbers in any range with the Secrets module

A=2	***B=3***	***C=5***	***Ç=8***	***D=13***	***E=21***	***F=34***
G=55	***Ğ=89***	***H=144***	***I=233***	***İ=377***	***J=610***	***K=987***
L=1597	***M=2584***	***N=4181***	***O=6765***	***Ö=10946***	***P=17711***	***R=28657***
S=46368	***Ş=75025***	***T=121393***	***U=196418***	***Ü=317811***	***V=514229***	***Y=832040***
Z=1346269	***.=2178309***	***,=3524578***	***?=5702887***	***!=9227465***		

Table 1. Numerical terms corresponding to letters

A=1	***3.3+56=65 B=27(adım sayısı)***	***5.3+12=27 C=111(1e inmek ıcın adım sayısı)***	***8 Ç=3 adım sayısı***	***13.3+79=118 D=33 adım***	***3.21+80=143 E=103***	***34 F=13***
55.3+35=200 G=26	***89.3+31=298 Ğ=24***	***144 H=23***	***233.3+23=722 I=46***	***377.3+38=1169 İ=57***	***610 J=38***	***987.3+27=2988 K=48***
1597.3+52=4843 L=165	***2584 M=102***	***4181.3+31=12574 N=107***	***6765.3+36=20331 O=74***	***10946 Ö=161***	***17711.3+50=53183 P=78***	***28657.3+41=86012 R=195***
46368 S=145	***75025.3+11=225086 Ş=111***	***121393.3+99=364278 T=91***	***196418 U=129***	***317811.3+26=953459 Ü=170***	***514229.3+67=1542754 V=194***	***832040 Y=131***
1346269.3+18=4038825 Z=198	***2178309.3+78=6535005 .=209***	***3524578 ,=128***	***5702887 ?=245***	***9227465 !=119***		

Table 2. Coded (Iterative) numerical terms corresponding to letters

Now, let us present the Python code required to generate Table 2 above—specifically, to calculate the number of steps in the Collatz process. Additionally, the Python code provided below also generates graphs that visualize how the values change throughout the sequence. These graphs demonstrate that the numbers do not follow a fixed rule or pattern but instead emerge from random-like behavior, with values sometimes rising sharply and at other times decreasing significantly:

```
def collatz_steps(n):
    """Calculates the number of steps in the Collatz Conjecture for a given number and returns the step count along with the sequence."""
steps = 0
sequence = [n]  # To store the sequence of values
while n != 1:
if n % 2 == 0:  # If the number is even
n = n // 2
else:  # If the number is odd
n = 3 * n + 1
sequence.append(n)
steps += 1
return steps, sequence
# Get input from the user
number = int(input("Enter a number: "))
# Run the Collatz process
steps, sequence = collatz_steps(number)
# Display results
print(f"The Collatz process for {number} completed in {steps} steps.")
print("Sequence of operations:")
print(sequence)
# Plot the graph (optional)
import matplotlib.pyplot as plt
plt.figure(figsize=(10, 6))
plt.plot(sequence, marker='o', linestyle='-', color='b')
plt.title(f"Collatz Conjecture Graph ({number})")
plt.xlabel("Step")
plt.ylabel("Value")
plt.grid()
plt.show()
```

The following figures, obtained using the Python code above, represent iterative graphs derived from what we may refer to as the generalized Collatz process. These are part of the Kakutani-based random number encoding system and clearly demonstrate that the numerical values deviate significantly from any fixed or regular pattern, producing both very large and relatively small numbers throughout the iterations.

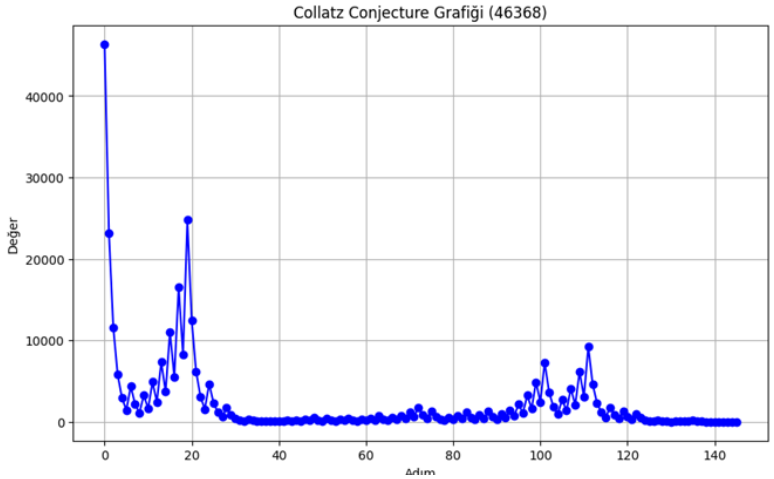

Fig 4. Kakutani distribution corresponding to the number 46368

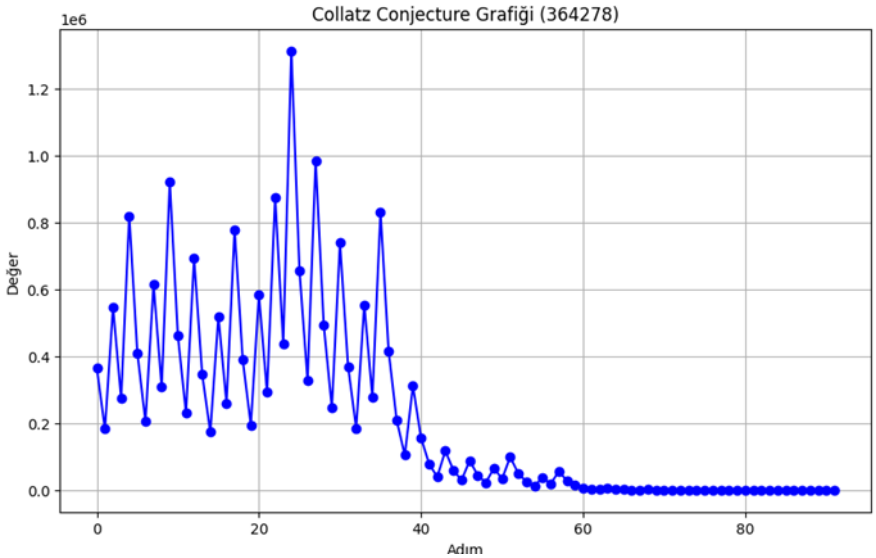

Fig 5. Kakutani distribution corresponding to the number 364278

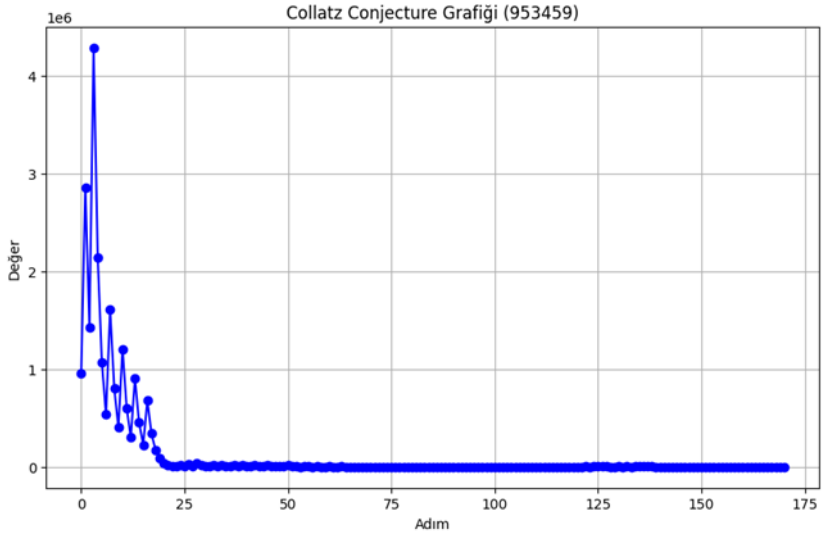

Fig 6. Kakutani distribution corresponding to the number 953459

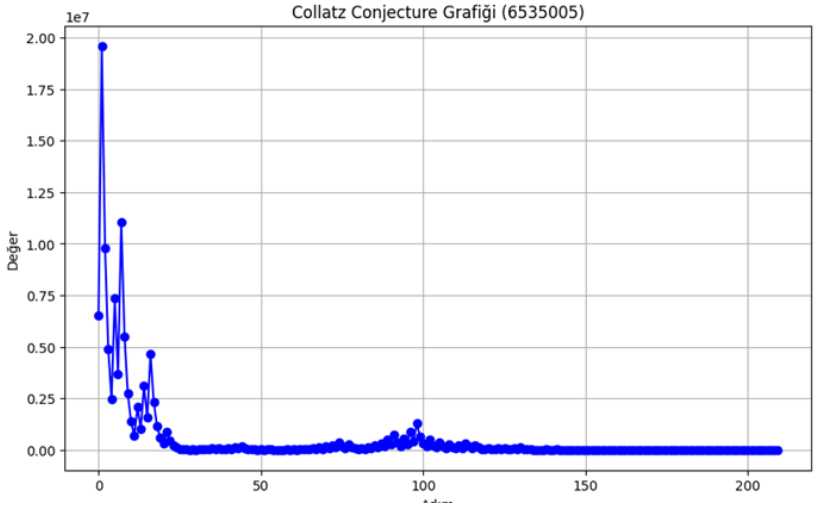

Fig 7. Kakutani distribution corresponding to the number 6535005

As can be seen from the figures above, both very large and relatively small values exhibit irregular jumps and are distributed at varying frequencies without following a specific pattern. Such erratic and unpredictable behavior directly echoes the foundational principles of quantum mechanics. Concepts such as the uncertainty principle, superposition, and randomness in the quantum realm not only symbolize this irregularity but also utilize it systematically to ensure security. In particular, quantum cryptography employs this inherent randomness and uncertainty as a fundamental tool in secure key distribution and data protection. Thus, these chaotic and seemingly unpredictable distributions become a metaphor for the robust and reliable structure of quantum encryption.

The graphs and analyses presented below illustrate the entropy variation of encoded letters obtained after the Kakutani transformation, along with a corresponding heatmap.

In the graph:

- **X-axis:** Letters, each associated with a unique Fibonacci number (e.g., B, C, D, …, Z).
- **Y-axis:** Shannon entropy of the Kakutani transformation sequence generated from the corresponding Fibonacci number and a randomly assigned value.

General Observations and Interpretations

1. Small Fibonacci Numbers (e.g., B, C, D)

- These letters correspond to small numbers $(e.g., 3, 5, 13)$.
- The Kakutani transformation terminates quickly → limited variability in the sequence.
- Entropy values are low.

Interpretation:

These characters carry low information density. Their transformation processes are more deterministic and predictable.

2. Medium-sized Fibonacci Numbers (e.g., I, İ, K, L, N)

- Numbers in the range of 200–4000 generate more transformation steps.
- The sequences exhibit both small and large values → increased diversity.
- Moderate to high entropy levels are observed.

Interpretation:

These letters represent an intermediate zone where information density increases and transformations start to exhibit chaotic behavior. They display a hybrid structure between randomness and order.

3. Large Fibonacci Numbers (e.g., Z, Ü, V)

- These correspond to very large numbers (e.g., 1,346,269).
- The transformation is prolonged, with frequent and substantial value changes, producing many unique outputs.
- Entropy values are high.

Interpretation:

These characters reflect the highest level of quantum-like randomness and information density. They generate unpredictable, chaotic structures and represent areas of maximal encryption strength.

In Summary:

- "As entropy increases, so does the system's information-carrying capacity and resistance to decryption."
- "This graph serves as concrete evidence that our algorithm exhibits quantum-like behavior."
- "While low-entropy letters behave deterministically, high-entropy letters form chaotic structures that create a powerful cryptographic shield."
- "Transformations initiated by large values, such as the letter Z, offer encryption strength that surpasses classical systems."

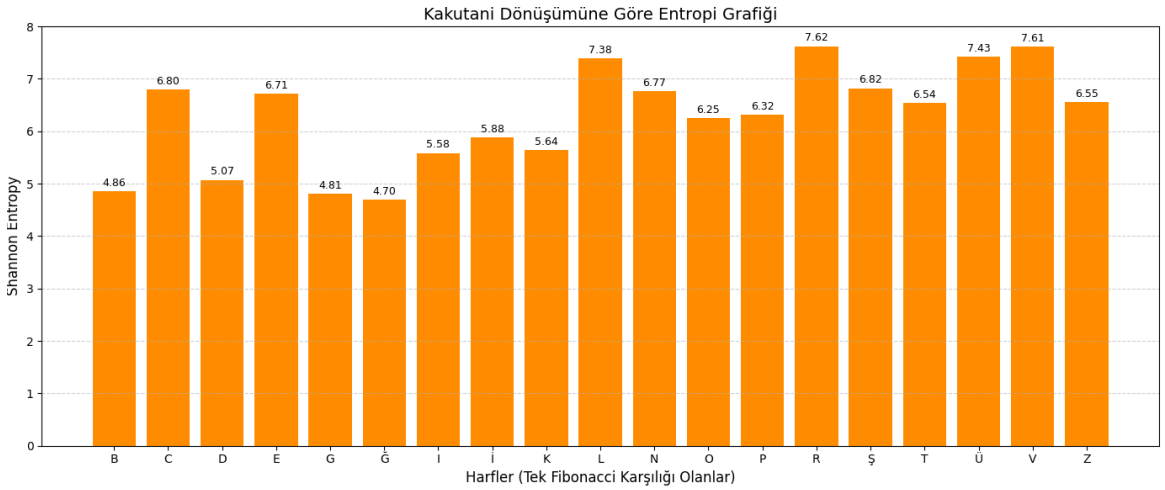

Fig 7. Entropy graph according to Kakutani transformation (single value terms of Fibonacci number)

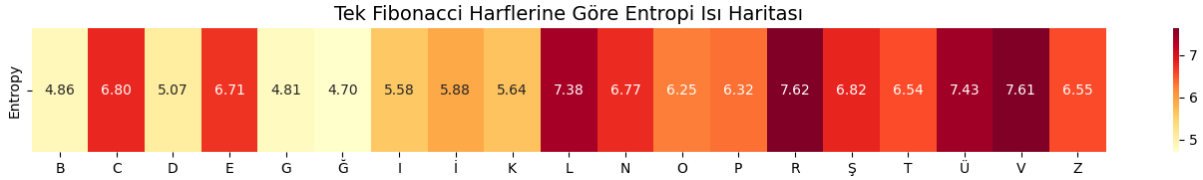

Fig 8. Heatmap of letters corresponding to single-valued Fibonacci numbers

• Light color → low entropy (simple transformation)
• Dark red → high entropy (complex, unpredictable transformation)

4. Results

This study proposes an innovative encryption algorithm that integrates random number generation, Fibonacci sequences, and generalized Collatz transformations (specifically, the Kakutani conjecture), offering a novel approach in the field of information security. By leveraging the interaction between randomness and mathematical structures, the algorithm creates a robust encryption system that is resilient against potential threats posed by quantum computers.

The combination of the Fibonacci sequence's regularity with the chaotic nature of Collatz transformations significantly enhances the unpredictability of the algorithm, thereby increasing the overall security of the encryption process. As a result, the system yields encryption outputs that can only be decrypted by the algorithm's designer. Additionally, the integration of iteration processes and random numbers enhances the flexibility of the system, ensuring unique outcomes in each encryption operation.

Developed using artificial intelligence and Python's powerful mathematical libraries, this algorithm represents an important step toward the future of cryptographic systems. AI-driven optimizations improve both the performance and security of the algorithm while providing a fresh perspective on the potential of quantum-resistant encryption techniques.

In conclusion, this study contributes to both mathematical theory and modern cryptographic applications by offering a robust and innovative solution for future security challenges. Algorithms developed to fortify security in the quantum era, such as this one, are capable of addressing the ever-growing security demands of the digital world and lay the groundwork for next-generation encryption systems.

5. Recommendations

The encryption algorithm proposed in this study enhances security by combining random number generation with mathematical transformations. However, there are several improvements that could further enhance its effectiveness.

First, the use of **Quantum Random Number Generators (QRNGs)** could strengthen resistance against quantum computing threats, making the encryption even more secure. Second, testing the algorithm with generalized Fibonacci sequences (such as **k-Fibonacci numbers**) could reveal its versatility and highlight its strengths.

Additionally, incorporating artificial intelligence techniques to accelerate the encryption process and reduce computation time could significantly improve the algorithm's efficiency. Finally, testing the algorithm in real-world scenarios would help identify potential vulnerabilities and validate its practical robustness.

These recommendations, if implemented, would not only enhance the security and performance of the algorithm but also establish a strong foundation for future encryption systems.

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INVESTIGATION OF POSSIBILITIES OF PRODUCING BIODEGRADABLE ORGANIC GROWING MEDIA FOR PLANT PRODUCTION USING A RESIGNED HYDRAULIC PRESS

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ABSTRACT
Polymer materials, which are obtained from fossil fuels and used as plastic materials in our daily lives, create large amounts of solid waste and cause great environmental pollution. As an agricultural country, our country produces large quantities of waste due to agricultural production activities. Some of the waste material released is the plastic growing media (seedling growing, etc.) used during the production phase. The other important part is the agricultural waste left on the land. However, it is important that these wastes can be turned into utilizable products and returned to the country's economy. In this sense, biomass is a rich source of carbon and biomass carbonaceous materials have a wide range of applications due to their low cost, abundance and diversity of transformations, environmental friendliness and superior physical/chemical stability. At this point, it is of great importance that these wastes are stored and used for conversion systems into different valuable products. This study will try to produce a biodegradable plant growing place by using both the unused harvest and threshing wastes that come out as a result of agricultural activities and the poultry litter that comes out as a result of poultry farming. A redesigned computer-controlled hydraulic press capable of pressing 100 tons will be used for biodegradable growing places. Molds with different geometrical properties are designed for the wastes released, and plants' growing environments will be obtained in these molds. The quality parameters of the obtained growing media for durability and their ability to dissolve in the soil will be investigated, and the most suitable mold geometry will be determined. In addition, it will try to prevent environmental pollution by reducing the use of fossil-based plastic materials used in plant cultivation, especially in greenhouse cultivation.

Keywords: Agricultural waste, poultry litter, growing place, hydraulic press, mold

Introduction

Although significant amounts of agricultural organic waste are produced in our country every year, a large portion of this waste is not evaluated and is either disposed of by dumping in landfills or burned (Tabasaran, 2018; Sertgümeç et al., 2021). In order to contribute to the national economy, these organic wastes need to be evaluated. Studies on the evaluation of wastes are increasing in our country and good results have been obtained from the studies conducted recently (Akinci et al., 2008; Bilgili et al., 2023). For this reason, transferring the existing knowledge to practice after laboratory-scale studies and developing such systems for the conditions of our country will enable the evaluation of organic wastes.

Today, the material of the era is referred to as plastics. The wide range of application areas of plastics provides an industrial advantage and due to the wide range of application areas, it causes the formation of large amounts of plastic waste every year all over the world (Raj et al., 2025). It is estimated that the annual amount of plastic produced worldwide in 2015 will cost the global economy trillions of dollars and the annual amount of plastic will exceed 300 million tons (WPP, 2016; Hamid et al., 2021). The majority of the plastics produced are made from petroleum-based materials and these polymeric materials made from petroleum resources harm the environment as waste (Emad et al., 2011; Reddy et al., 2013). In recent years, the demand for the use of waste, non-renewable resources and natural products for the solution of environmental problems has increased. Renewable resources have a positive effect on the environment. Bio-based materials obtained from renewable resources on a cost-performance basis can partially or in some cases completely replace petroleum-based materials (Lligadas et al., 2013). Currently, With the increasing environmental problems such as decreasing fossil resources and greenhouse gas emissions, the focus has been on the development of environmentally friendly polymer compounds (Chieng et al., 2014). Nowadays, most common polymers are derived from polymers and oils obtained from renewable resources (Gramlich et al., 2010). Since bioplastics are obtained from both biological and fossil resources, they occupy a large place in the field of thermoplastics. Most of the research is carried out to obtain new compounds from biological sources by both industrial biotechnology and chemical methods (Reddy et al., 2013). This reduces the consumption of fossil fuels and the dependence on harmful substances (Chieng. et al. 2014). It is desired that polymers used in daily life are replaced by polymers from renewable sources (Sugasit, 2011; Gramlich et al., 2010).

The class of renewable source bioplastics includes starch, cellulose, proteins, lignin, chitosan, polylactic acid and polyhydroxyalkanoates/polyhydroxybutyrates (Reddy et al. 2013). One of the favorite materials for the production of high performance, environmentally friendly, biodegradable polymers is aliphatic polyesters. Polylactic acid (PLA), which is a liner aliphatic polyester, is considered the most promising polymer instead of petroleum-based polymers due to its mechanical characteristics such as tensile strength and Young's modulus similar to polyethylene terephthalate (PET) and nylon (Sawai et al., 2002; Gupta et al., 2007; Xiong et al., 2013; Chieng et al. 2014). In this study, it will be attempted to produce biodegradable plant growth media using both unused harvest and threshing wastes generated as a result of agricultural activities and poultry litter generated as a result of poultry farming. A redesigned computer-controlled hydraulic press with a 100-ton pressing capacity will be used for the biodegradable growing medium. Molds with different geometric features have been designed for the waste released and growing mediums for plants will be obtained in these molds. The quality parameters and soil dissolution capabilities of the obtained growing mediums will be investigated to determine the most appropriate mold geometry. In addition, the use of fossil-based plastic materials used in plant cultivation, especially in greenhouse cultivation, will be reduced and environmental pollution will be prevented.

Materials and Methods

Design criteria were determined for the molds designed for the production of cylindrical and square plant growing environments with a hydraulic press with a pressing capacity of 100 tons, and detailed design drawings were created using CAD software (Figure 1).

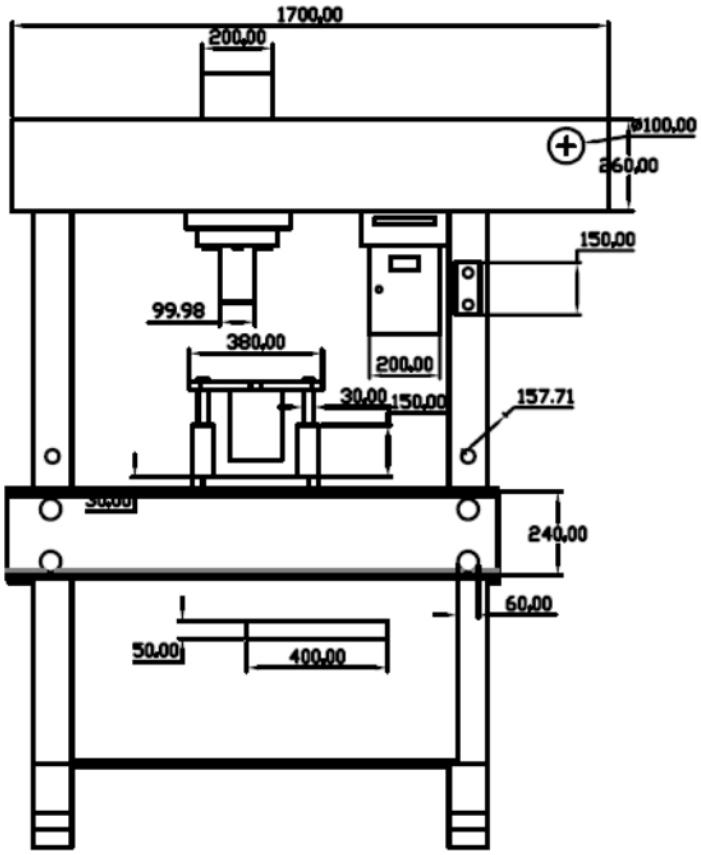

Figure 1. Front view and dimensions of the hydraulic press

Findings and Discussion

As the first step for the redesign and manufacturing process, new design criteria were determined for the hydraulic press with a pressing capacity of 100 tons. High strength steel and other suitable materials were selected for the durability of the press and molds (Sd52 and Sd 4140). The procurement process of materials was initiated. Steel plates and other materials were cut and shaped with CNC machines in accordance with the determined design. The cut parts were welded and joined. In the assembly phase, the main body of the press and the molds were brought together (Figure 2). Hydraulic cylinders, pumps and valves were assembled, and the hydraulic system was subjected to leakage and pressure tests. After the production and manufacturing process of the hydraulic press was completed, the press and molds were subjected to various load and performance tests.

Figure 2. Views from the hydraulic press assembly phase

The durability of the production environments to be produced from the molds depends on the durability of the material, the structural integrity not being damaged, the permeability of moisture and air, and the shape and size stability for ease of use. Creating these factors is a very detailed and meticulous process. At the beginning of this process, the careful selection and preparation of the materials to be used takes place. In addition, high-strength and wear-resistant materials were used in the selection of materials and the hardness of the material was increased by applying heat treatment. Since the smoothness of the inner and outer surfaces is important for reducing friction and increasing product quality, surface quality was improved with coating or polishing processes (Figure 3).

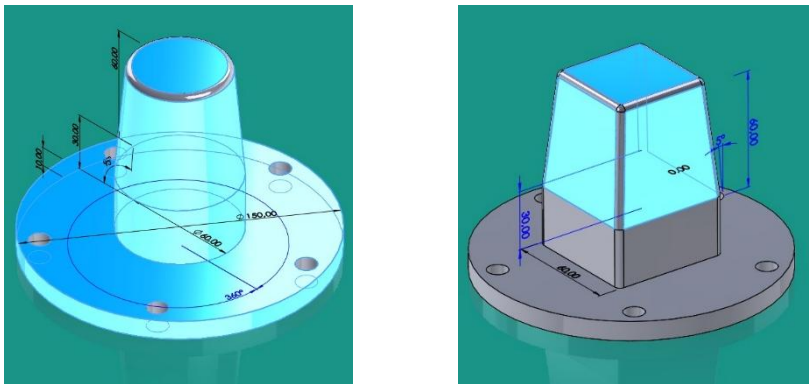

Figure 3. Dimensions and appearances of cylindrical and square molds

A heating system is installed in both molds to allow the material to be removed from them more quickly and easily. With this heating system, the mold temperature can be increased up to 200ºC (Figure 4).

Figure 4. Mold heating system

Pressing Process

The hydraulic press is operated according to the programmed pressure and time settings. The press, which has a pressing capacity of 100 tons, will be able to compress the material under high pressure and give it the desired shape and density. At this stage, the material must be compressed homogeneously and reach the desired density. During the pressing process, parameters such as pressure, temperature and position will be continuously monitored (Figure 5).

Figure 5. Pressing process

Extraction and Drying

After the pressing process is completed, the molds are opened and the plant growth media are carefully removed. The removed products will be transported and dried in a way that will preserve their shape. The drying process ensures that the material hardens and increases its durability. In this process, the physical integrity of the products will be preserved and they will be made resistant to external factors (Figure 8).

Finally, the produced plant growing media will be subjected to quality control tests. These tests check whether the products comply with criteria such as density, durability and homogeneity. As a result of these tests, the plant growing media will be solid, durable and ready for use.

In the machine manufactured for the plant growing environment with a pressing capacity of 100 tons, some structural problems arose in the later stages of the production process. These problems arose from unforeseen stress and load distribution problems in the design of the machine. In particular, it was anticipated that changes would be appropriate in some parts in order to prevent deformations or cracks in the main carrier structure of the machine. In order to solve these structural problems, some analyses were conducted with the company to try to determine the source of the problem. As a result of the analyses, it was understood that material changes and design modifications were required in some critical components of the machine. The implementation of these changes and the production of new components took longer than expected. Additional tests and quality control processes were also required to verify the changes made. These tests were meticulously performed to ensure that the machine operated safely and efficiently.

In addition, some software-related errors occurred after production in the operation of the machine manufactured for the plant growing environment with a 100-ton pressing capacity. These errors occurred in the automation systems and control software of the machine and prevented the machine from operating efficiently. These errors in the control software of the machine caused the data from the sensors to be misinterpreted and the wrong commands to be given accordingly. This situation caused some functions of the machine to stop unexpectedly or to operate incorrectly.

Together with the software team, a comprehensive review was conducted to identify and fix these errors. First, the software codes were reviewed in detail and potential error sources were identified. During this process, it was understood that some algorithms needed to be optimized and data processing methods updated. In addition, additional security checks and error correction mechanisms were added to make the software more stable and error tolerant.

In the process of correcting the software errors, all the functions of the machine had to be retested and verified. These tests were carried out meticulously to ensure that the machine operated safely and efficiently under different operating conditions.

Conclusion

In redesigned machines, machine design studies include many complex and challenging processes. Selecting the right materials is critical to the durability and performance of the machine. The manufacturing process requires high precision and quality control. Errors that may occur during manufacturing may require costly and time-consuming corrections. During the design and planning phase, detailed engineering analyses and simulations were performed to increase the functionality and efficiency of the machine. In the material selection and procurement process, the most appropriate materials were selected and procured by considering criteria such as durability and cost. During the manufacturing phase, the parts were precisely processed and manufacturing processes were carried out. The functionality and accuracy of the machine were checked with post-manufacturing tests and the necessary adjustments were made. All of these processes will ensure that the machine reaches the planned performance criteria and contributes to the overall goals of the project. The proper operation of the machine is the most important factor in the success of the project and the potential to create the expected impact. Depending on this situation, plant growing environments with the desired characteristics can be produced and the sustainability of the project will be ensured.

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INVESTIGATION OF POSSIBILITIES USING SNACK PUMPKIN VEGETABLE WASTES IN PELLET BIOMASS PRODUCTION

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ABSTRACT
Evaluating agricultural waste is an important process that contributes to reducing environmental problems and increasing economic benefits. These reuse processes help dispose of agricultural waste without harming the environment while encouraging a circular economy approach. In particular, energy production from biomass reduces carbon emissions by reducing fossil fuel use and contributes to the fight against climate change by increasing access to sustainable energy sources. In this study, the evaluation of the root zone of the snack pumpkin plant formed during agricultural production as pellet biomass was investigated and an attempt was made to present an important recycling and sustainability solution in both environmental and economic terms. For this purpose, some physical and strength properties were determined for pellets obtained with different properties. The moisture content for the snack pumpkin root zone waste was 10.9% at 8 mm particle size, 12.80% at 10 mm diameter, and the highest material density value was 248.5 g. The highest values obtained in the pressure test were calculated as 0.650 kN in 8 mm diameter and 0.585 kN in 10 mm diameter, respectively; the highest values in the mechanical strength test were calculated as 97.82% in 8 mm diameter and 96.44% in 10 mm diameter, and 91.25% in 8 mm diameter and 90.24% in 10 mm diameter in the breaking resistance test. The bulk densities of the pellets varied between 1533.85 mm^3 and 1783.04 mm^3. For these determined properties, it is thought that the pellet biomass of the snack pumpkin plant can be evaluated as an alternative biomass source with pellet properties that comply with the standards and will also create a circular economic solution that aims to provide both environmental responsibility and economic gain.
Keywords: Agricultural waste, snack pumpkin, biomass, pellets

Introduction

Biomass, which is among the renewable energy sources, has many advantages for fuel production. Solid, liquid and gaseous fuels etc. are obtained from biomass sources as a result of various processes and heat and electricity production is possible as a result of burning these fuels (Ali et al., 2024; El-Araby, 2024; Bisht and Pandey, 2025). However, biomass sources can be used not only for energy production but also for the production of food and some chemicals in many areas. In addition, biomass stands out as an environmentally friendly fuel since it does not contain the environmentally harmful substances and sulfur found in fossil fuels. With these features, the fact that it will continue in plant production as long as solar energy exists makes biomass an inexhaustible energy source (Mignogna et al., 2024).

One of the easiest and most effective methods to produce energy from agricultural residues is to use them as solid fuel. In recent years, it has become very important to use agricultural residues as solid fuel as an effective energy source. One of the most effective ways to use agricultural residues as a solid energy source is to turn them into pellets. In recent years, the importance of pelletizing has increased, and the use of pellets has become quite widespread.

Knowing the physical properties of biomass pellets is very important especially in terms of transportation, storage, shipping processes and combustion systems. Physical properties of pellets are their dimensions as shape, diameter and length, density, porosity, hardness and durability (Liu et al., 2014). Dimensions such as length and diameter of pellets are very important in terms of combustion processes and design of combustion systems. First of all, pellets provide a better combustion rate especially in small capacity combustion systems, while pellet length is important in terms of automatic feeding of fuel to the combustion system, shorter pellets provide a more comfortable flow (Lehtikangas, 2001). Pellet density affects transportation costs, transportation and storage efficiency. Pellets obtained with higher density reduce transportation costs and increase transportation and storage efficiency (Lehtikangas, 2001, Mani et al., 2006; Tumuluru et al., 2010).

It is very important that the pellets remain durable until they reach the end user. Pellets with high durability provide advantages especially in transportation, handling and storage (Lehtikangas, 2001). Pellet durability values of 80% and above are considered high quality, 70-80% are considered medium quality and below 70% are considered low quality (Tabil and Sokhansanj, 1996; Tabil and Sokhansanj, 1997).

In this study, it was aimed to pelletize the residues of the squash plant remaining in the field after drying and grinding them with a 5 mm sieve diameter, to determine the physical properties related to the quality of the pellets and to measure the flue gas emission values by burning the pellets in a pellet stove. The pelletizing process was carried out with two different moisture contents, 8-10% and 10-12%, and two different pellet diameters, 6 mm and 8 mm. Regarding the physical properties of the obtained pellets, the pellet piece and bulk density, moisture content, moisture absorption status, mechanical strength resistance and pressure resistance were determined by physical tests and the classification process was carried out using the image processing technique. In addition, this study is the first study in our country in terms of evaluating the squash residues by pelletizing.

Materials and Methods

Pumpkin seed cultivation is mostly carried out in the Central Anatolia Region. In the Central Anatolia Region, Nevşehir, which accounts for 35% of Türkiye's snack pumpkin production, ranks first in production. Kayseri follows with 29% and Konya with 11% (TÜİK, 2020). According to TÜİK 2020 data, snack pumpkin production in Kayseri is carried out on

an area of 358,625 da and 16,920 tons of product are obtained. The highest snack pumpkin production in Kayseri province is carried out in Tomarza, Develi, Talas, and Yeşilhisar districts, respectively (TÜİK, 2020). In this study, snack pumpkins grown at Erciyes University Agricultural Research Center were used. Snack pumpkin is a plant grown in the Central Anatolia Region. Snack pumpkin is also quite sufficient in terms of molasses content. In this way, it was sufficient to work with only the collected residues without the need for any binder in the pellet production process in the study. The resulting snack pumpkin agricultural residues were dried in a natural environment to remove the gross moisture.

In the tests applied to pelletize the residual material and determine the physical properties of the pellets;

- Blade type mill with 7.5 kW power and 2800 rpm rotation speed,
- Pelletizing machine with 10 hp/7.5 kW engine power and 50-75 kg/h capacity,
- Precision scale with 0.01 g sensitivity,
- Sieve analysis set,
- Mechanical durability test device with 50 rpm rotation speed,
- Pressure test device,
- Drying oven,
- Air conditioning cabinet (incubator),
- Calorimeter,
- Muffle furnace,
- Pellet stove,
- Electrochemical flue gas analyzer was used.

In the study, snack pumpkin agricultural residues obtained after harvest from agricultural production areas were used as the pelleting material and the pelleting process was carried out at two different moisture contents (Figure 1). Considering the European Union standards, the most suitable moisture content values for the pelleting process are in the range of 8-10%. However, since no previous study has been conducted for the snack pumpkin plant determined for this study, the pelleting process was also carried out at a second moisture range of 10-12%.

Figure 1. Material before grinding

A laboratory scale, flat die circular perforated pelletizing machine with 10 hp/7.5 kW motor power and 50-75 kg/h capacity was used for pelletizing the material. Pellet trials were carried out with different pellet diameters and 2 different moisture contents for each sample as 8-10%

and 10-12%. The pelletizing process was carried out by continuously feeding the ground material to the pelletizing machine. As a result of the pelletizing process, pellets with the desired properties were obtained with diameters of 6 and 8 mm (Figure 2).

Moisture content: 8-10%, Pellet diameter: 6 mm

Moisture content: 10-12%, Pellet diameter: 6 mm

Moisture content: 8-10%, Pellet diameter: 8 mm

Moisture content: 10-12%, Pellet diameter: 8 mm

Figure 2. Appearance of the obtained pellets

Findings and Discussion
Material Sieve Analysis

In accordance with the purpose of the study, the agricultural residues of the snack pumpkin plant used in the experiments were subjected to sieve analysis after drying and grinding processes in order to determine the particle size of the material. The sieve analysis results are given in Table 1.

Table 1. Sieve analysis data

Sieve Opening (mm)	10	8	7.1	5	4	2.8	2	1	1<
Weight (g)	5.06	3.37	4.92	32.80	8.19	19.30	11.48	9.31	2.26
Weight (%)	%5.06	%3.37	%4.92	%32.80	%8.19	%19.30	%11.48	%9.31	%2.26

When Table 1 was examined, it was seen that the particle size distribution of the snack pumpkin agricultural residue was obtained as 60.29 g in the range of 3-5 mm.

Evaluation of Material and Pellet Density

Tests to determine the material density were repeated 5 times and the mean repetition was recorded as 533.01 g.

The effects of the moisture content of the material and the pellet diameter width on the pellet volume density and pellet density are given in Table 2.

Table 2. Density data of pellets

Pellet Moisture Content (%)	8-10		10-12	
Pellet Diameter (mm)	6	8	6	8
Pellet Density (kg.m^{-3})	546.26	494.73	560.93	493.90
Volume Density (kg.m^{-3})	616.01	530.21	640.55	528.83

When the values in Table 2 were examined, the highest pellet volume density was determined as 640.55 kg.m^{-3}, while the lowest pellet volume density was determined as 528.83 kg.m^{-3}. In addition, the highest pellet density was determined as 560.93 kg.m^{-3}, while the lowest pellet density was determined as 493.90 kg.m^{-3}.

In the EN 14961-3 European Union Standard, it is stated that the volume density for EN plus-A1, EN plus-A2 and EN-B class pellets should be ≥600 kg.m^{-3}. Although the values specified in EN 14961-3 include wood pellets, it was observed that the volume density values of the snack pumpkin pellets we obtained were quite close to this value.

Mechanical Durability Tests

Durability tests are important for defining the characteristics of pellets, especially those transported by pneumatic or mechanical systems, and durability resistance tests help control the compression process and therefore the pellet quality in the manufacturing industry. Pellets with high durability resistance are defined as high quality pellets (Kaliyan and Morey, 2009).

Table 3. Mechanical durability test values

Pellet Moisture Content (%)	8-10		10-12	
Pellet Diameter (mm)	6	8	6	8
Shatter Resistance (%)	99.05	98.41	98.80	93.66
Mechanical Strength (Tumbler) Resistance (%)	97.45	90.72	96.83	88.08

The effects of the moisture content of the material and the pellet diameter width on the mechanical strength resistance of the pellets were investigated using the Tumbler test. Table 3 is given.

When the values in Table.3 are examined, the highest mechanical strength value was found to be 97.45% and the lowest value was found to be 88.08%.

In the studies conducted by Tabil and Sokhansanj (1996), Tabil and Sokhansanj (1997) stated that the pellet quality is good when the pellet durability resistance is 80% and above. The mechanical durability values of the pellets obtained from snack pumpkin residues at 8-10% and 10-12% moisture content were parallel to the literature data.

In the EN 14961-3 European Union Standard, the value of ≥%97.5 for EN plus-A1, EN plus-A2 class pellets and ≥%96.5 for EN-B class pellets was specified, and it was observed that the durability values of the obtained snack pumpkin pellets were below these values. In addition, an increase in the mechanical durability value occurred with the decrease in pellet diameter.

When the shatter values of the pellets were examined, the highest shatter resistance was obtained as 99.05% at 8-10% moisture content and 6 mm pellet diameter, and the lowest as 93.66% at 10-12% moisture content and 8 mm pellet diameter. Although Tabil and Sokhansanj (1996) and Tabil and Sokhansanj (1997) stated that pellet quality is good when the pellet durability resistance is 80% and above, it is stated that the durability resistance of wood pellets should be ≥97.5 in the ENplus-A1 and ENplus-A2 class pellet standards of the European Pellet Council, and ≥96.5 in the EN-B class pellet standards. When these standards are taken into consideration, it has been determined that the obtained pellets comply with the ENplus-A1, ENplus-A2 and EN-B class standards in terms of shatter resistance.

Ash Content and Calorific Values of Pellets

The calorific values of the fuels are the amount of heat released as a result of the complete combustion of the unit weight of fuel, and the ash content and upper calorific values of the pellets obtained from the agricultural residues of pumpkin for snacks at two different moisture contents are given in Table 4.

When the values given in Table 4 are examined, the upper calorific value was obtained as 17.16 $MJ.kg^{-1}$. In addition, the ash content obtained as a result of burning the pellets obtained from snack pumpkin residue was found to be 8.24%.

Table 4. Ash contents and upper calorific values of snack squash agricultural residues

	UpperCalorific Value ($MJ.kg^{-1}$)	**Ash Content (%)**
Snack Pumpkin	17.16	8.24
Pine talaşı peleti	18.93	12.55
Mdf tozu peleti	16.15	11.45
Lignite Kömürü	20.51	16.45

The calorific value for EN plus-A1, EN plus-A2 and EN-B class pellets is specified as Q≥16 MJ/kg in the European Union EN 14961-3 Standard. It was observed that the calorific values of the pellets obtained from snack squash are in accordance with the values specified in the EN 14961-3 standard. In addition, the calorific values of the pellets obtained from snack

squash plant residues are similar to other fuels, which again shows that this pellet fuel can be used as an energy source.

In the European Union EN 14961-2 standard, ash contents are specified as ≤0.7% for EN plus-A1, ≤1.5% for EN plus-A2, and ≤3.0% for EN-B. Although these values are specified for wood pellets, the ash contents of the obtained snack pumpkin pellets were determined to be above these values.

When the calorific values and ash content values are compared, the moisture and ash content values of the material negatively affect the combustion quality. Therefore, higher calorific values are obtained from pellets with low moisture and ash content.

Conclusion

Considering the results of this study, repeatable and most suitable pelleting parameters can be determined for different mold features and different particle sizes.

Especially in regions with high agricultural waste potential, mobile or fixed pelletizing facilities should be established in order to develop the local people and these biomass energy sources with significant potential should be added to the economy.

The widespread use of biomass energy as a clean and renewable energy source will not only be of great importance in terms of environment due to low carbon emissions but will also make great contributions to our country in terms of economy. For this reason, studies on biomass energy should be supported by the relevant institutions and the development of new systems should be supported.

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SEASONAL AND SPATIAL DISTRIBUTION OF PCB CONCENTRATIONS IN THE ATMOSPHERE OF A METROPOLITAN CITY: ISTANBUL, TÜRKİYE

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ABSTRACT
This study focuses on determining the atmospheric concentrations and possible sources of polychlorinated biphenyl (PCB) compounds. Between May 2011 and April 2012, atmospheric concentrations of PCBs were measured monthly in three different areas of the city: urban, semi-rural and industrialized. The levels of PCBs were compared with the measurements made in different regions and the gas-particle phase distributions in the atmosphere were analyzed. In addition, environmental dynamics and transport mechanisms of PCBs were evaluated by comparing possible sources with meteorological data. According to the measurement results, the average particle phase concentration of PCBs was 84.05±5.16 pg/m³ and the gas phase concentration was 889.1±112.25 pg/m³ in Davutpaşa, an industrial area. In Beşiktaş, an urban area, the average concentrations for particulate and gaseous phases were 74.81±4.96 pg/m³ and 559.831±53.62 pg/m³, respectively. In Fenertepe, which has semi-rural characteristics, average values of 57.48±5.72 pg/m³ in the gas phase and 15.20±1.68 pg/m³ in the particulate phase were recorded. The dispersion of PCBs in the atmosphere may vary depending on temperature, wind speed and other weather conditions. The data obtained showed that the high concentrations of PCBs, especially in the gas phase, are due to environmental factors and that these compounds are easily transported in the atmosphere. This study emphasizes the importance of developing more effective policies and strategies to control PCBs that harm the environment and human health.
Keywords: Polychlorinated Biphenyls (PCBs), Atmospheric Concentration, Gas-Particle Distribution, Source Analysis, Environmental Impacts

1. INTRODUCTION

Polychlorinated biphenyls (PCBs) are organic compounds known as chlorinated hydrocarbons (Nemerow and Agardy, 1998) which are manufactured commercially by chlorinated biphenyls and have no natural sources (Park, Wade and Sweet, 2001). PCBs have been used as electrical insulating fluids, in building materials, and as plasticizers and flame retardants in various consumer products (Pěnčíková et.al., 2018). They are emitted into the atmosphere from anthropogenic activities and they may be transported to long distances, deposited in areas of no PCB resources (Cindoruk, Esen and Taşdemir, 2007). Evaporation of PCBs found in soil and natural water resources may be one of the main sources of PCBs in the atmosphere. Waste recycling sites can also be considered as a source of PCBs (Shen, Chen, Huang et.al.,2009).

Chlorination of domestic waters and combustion of chlorinated organics may also cause the formation of some simple PCBs (Taşdemir, 1997). Although the amount of PCBs released into the atmosphere is lower than in the soil and/or water, evaporation of these compounds due to their semi-volatile characteristics or transport of particles carrying adsorbed/absorbed PCBs into the air by a variety of factors cause an increase in the PCB concentrations in the ambient air (Halsall, Lee, Coleman, Burnett, Jones and Jones, 1995).

The PCBs monitored in the atmosphere may generally be originated from combustion of PCB bearing materials, mass tranfers taking place in water/air or soil/air interfaces, evaporations from waste dumping areas and sludge drying processes (Taşdemir and Holsen, 2005).

PCBs have been the subject of significant research in the literature because of the persistence and adverse effects on the environment. Previous studies showed that physiological effects of PCBs are similar to dichloro diphenyl trichloroethane (DDT) (Falconer and Harner, 2000). Since the 1930s, PCBs have been industrially produced and used in agriculture and various industries. They have been utilized as plasticizers, in carbonless copy paper, lubricating oils, inks, laminating and impregnating agents, paints, adhesives, waxes, cement and plaster additives, casting agents, dedusting agents, sealing liquids, fire retardants, immersion oils, and pesticide extenders (Breivik, Sweetman, Pacyna, Jones, 2002). The production and use of PCBs were banned in many European countries at the end of 1980's (Vaccher et.al., 2018). Despite such prohibition atmospheric concentrations in remote areas have not been reduced or decreased very little. (Panshin and Hites, 1994; Baker and Eisenreich, 1990; Van Drooge et.al., 2001). These compounds are still substantially released into the environment and cause significant environmental problems due to improper disposal methods, open and uncontrolled use and accidental releases in the past applications PCB contamination continues to pose a significant environmental challenge globally, as these pollutants are still being released into the environment through the use and disposal of products containing PCBs. (Lehmann, Christensen, Maddaloni and Phillips, 2015). PCBs, when entered into the atmosphere, may have equilibrium partitioning between gas and particles phases depending on ambient temperature, concentration and physicochemical characteristics of particulate matters (Lohman, Harner, Thomas and Jones, 2000).

The determination of atmospheric concentrations of these pollutants is crucial due to their significant environmental impacts. Differantiating gas/particle partitioning of these compounds provides important benefit since it directly affects the atmospheric transportation, residence time and removal processes (Taşdemir, 1997; Falconer and Harner, 2000; Simcik, Franz, Zhang and Eisenreich, 1998). The aim of this study is to investigate the seasonal and spatial variation of ambient PCBs and to determine the relationship between PCBs and meteorological parameters. Partitioning of PCBs between gas/particle phases was also investigated.

2. MATERIAL AND METHOD

2.1. Sampling Area

The combustion of fossil fuels for domestic heating and energy supply, both from stationary sources (such as homes and industrial plants) and mobile sources (like motor vehicles), is a significant contributor to air pollution in Istanbul. Other sources, including landfilling and wastewater treatment plants, also play a role. Sampling sites were strategically selected to reflect this diverse source profile, ensuring that each site had distinct characteristics to capture the full range of variations in PCB compounds in Istanbul's atmosphere.

Three distinct sampling sites were identified: urban, semi-rural, and industrialized regions. The urban site (Beşiktaş) primarily represents emissions from residential areas and heavy city traffic. The industrialized site (Davutpaşa) includes residential zones and small-to-medium scale industrial activities. The semi-rural site (Fenertepe) features a large forested area with some residential settlements, serving as a background reference. All sampling locations are illustrated in Figure 1.

Figure 1. Map of the study area and locations of the sampling points

2.2. Sample Collection and Analysis

A monthly sampling campaign (3-7 days sampling duration for per month and a total of 12 samples) were carried out during May 2011 and April 2012 in all three sampling points using High Volume Air Sampler (Tecora Echo). The each sampling period (every month), used to ranging from a 72 – 198 h sampling for each sample and a total of 645 and 1900 m^3 of air volume. All sampling procedures were conducted in compliance with the reference Method EPA TO-9A (USEPA, 1999). 19 of PCB congeners (PCB#28, PCB#52, PCB#77, PCB#81, PCB#101, PCB#105, PCB#114, PCB#118, PCB#123, PCB#126, PCB#138, PCB#153, PCB#156, PCB#157, PCB#167, PCB#169, PCB#170, PCB#180) were analyzed in all samples. Concentrations were determined for every individual congener in gas and particle phases (TSP) separately. Meteorological parameters were also recorded using wireless meteorological stations (Davis Vantage Pro2) located at each sampling point in order to analyze the effect of meteorological conditions on gas/particle partitioning of PCBs. The recorded meteorological parameters are barometric pressure, temperature, humidity, wind velocity/direction, precipitation, dew point and evapotranspiration.

Before sampling, the filters were conditioned at 450°C for 5 hours, and the polyurethane foam (PUF) adsorbents were pre-cleaned in a Soxhlet extractor with acetone for 16 hours. After sampling, all filters and PUF samplers underwent extraction, cleanup, and fractionation procedures. Glass sample cartridges containing PUFs and quartz filters were separately extracted with toluene in a Soxhlet extractor for 20 hours. The samples were spiked with a $^{13}C_{12}$-labeled extraction standard solution. After extraction, the toluene extract was concentrated using a rotary vacuum evaporator, re-dissolved in hexane, and pre-cleaned by shaking with 10 mL of concentrated sulfuric acid at room temperature. The pre-cleaned hexane extract was then transferred onto a multi-layer silica gel column designed for anthropogenic compounds and eluted with hexane. Extract was concentrated with modified Kuderna-Danish concentrator down to 0,5-1mL. Fractionation is the separation of PCB congeners from other similar structures (PCDD/F, PBDE etc.) as the final step of preparation procedure. For fractionation, 1g florisil column was used with hexane as the extracting solvent. Hexane extract containing mono-ortho PCBs and no dioxin-like PCBs was concentrated using Kuderna-Danish concentrator to a volume about 0,5 mL. The final extract was concentrated under a pure nitrogen stream to a volume of 250 µL. Final extract was concentrated under pure nitrogen stream to 250µL, then 4µL of samples were injected to high-resolution gas chromatography/high-resolution mass spectrometry (HRGC-HRMS, Thermo Gas Chromatograph Trace GC Ultra-HRMS) for the chromatographic analysis of PCB congeners. GC: Trace GC Ultra equipped with autosampler Thermo Electron Corp. Tri Plus, column STX-500 (60 m x 0.25 mm, film 0.15 µm) Restek MS: Thermo Electron Corp. DFS operated in MID mode, reference gas Perfluorotributylamine (PFTBA). The system achieved a resolution (R10) of approximately 10,000. Standard solutions of [$^{13}C_{12}$-2,3,4,4'-tetraCB (60), $^{13}C_{12}$-3, 3',4,5,5'-pentaCB (127) and $^{13}C_{12}$-2,3,3',4,5,5' hexaCB (159)] were used to evaluate the recovery efficiency of the sampling process. The recovery rates were found to range from 71% to 103% for 13C12-2,3,4,4'-tetraCB, 84% to 117% for $^{13}C_{12}$-3,3',4,5,5'-pentaCB, and 69% to 114% for $^{13}C_{12}$-2,3,3',4,5,5'-hexaCB. Additionally, extraction standard solutions were used to assess the efficiency of the extraction process, with the corresponding recovery values summarized in Table 1.

Table 1. Extraction standart solutions and the recovery values

Extraction Standard Solutions	Filter	PUF
	Recovery Efficiency (%)	Recovery Efficiency (%)
$^{13}C_{12}$-3,3',4,4'-tetraCB (77)	93±9	94±11
$^{13}C_{12}$-3,4,4',5-tetraCB (81)	95±6	98±7
$^{13}C_{12}$-2,3,3',4,4' tetraCB (105)	81±17	86±16
$^{13}C_{12}$-2,3,4,4',5 tetraCB (114)	66±12	66±13
$^{13}C_{12}$-2,3',4,4',5 pentaCB (118)	67±11	70±12
$^{13}C_{12}$-2,3',4,4',5 pentaCB (123)	72±12	72±13
$^{13}C_{12}$-3,3',4,4',5 pentaCB (126)	84±17	94±12
$^{13}C_{12}$-2,3,3',4,4',5 hexaCB (156)	77±13	85±16
$^{13}C_{12}$-2,3,3',4,4',5 hexaCB (157)	72±13	77±14
$^{13}C_{12}$-2,3',4,4',5,5' hexaCB (167)	84±17	85±19
$^{13}C_{12}$-3,3',4,4',5,5' hexaCB (169)	76±13	78±15
$^{13}C_{12}$-2,3,3',4,4',5,5' heptaCB (189)	80±8	80±13

3. RESULTS AND DISCUSSION

PCB concentrations were analyzed individually for each sampling point to assess the spatial distribution of PCB compounds.

3.1. Davutpaşa Sampling Site

Davutpaşa sampling area encompasses a mix of sources, including residential and industrial settlements, as well as traffic-related emissions. Monthly total PCB concentration ranged from 32.11 pg/m^3 to 412.82 pg/m^3 having an average of 81.12 pg/m^3. Average concentration value of each congener for particle and gas phases were shown in Table 2 (Çelikten, 2013). Average concentrations of congeners for particle phase ranged from 0.04 pg/m^3 to 1.64 pg/m^3 while gas phase concentrations ranged from 0.03 pg/m^3 to 39.72 pg/m^3. PCB congeners in particle phase could not been detected in some months while PCB congeners in gas phase were generally detected during entire sampling period. In this study, distribution of percentage for 3CBs, 4CBs, 5CBs, 6CBs and 7CBs homologue groups during whole sampling period at particle phase were 22%, 12%, 21%, 27% and 19% respectively. This distribution for gas phase were 53% (3CBs), 21% (4CBs), 12% (5CBs), 10% (6CBs) and 3% (7CBs).

Table 2. Explanatory statistics of PCB results measured at Davutpaşa

PCB Congeners	Particle Phase (pg/m^3)		Gas Phase (pg/m^3)		Total Particle Phase (pg/m^3)	Total Gas Phase (pg/m^3)	Lowest Particle Phase (pg/m^3)	Highest Particle Phase (pg/m^3)	Lowest Gas Phase (pg/m^3)	Highest Gas Phase (pg/m^3)
	Ave.	SD	Ave.	SD						
PCB 77	0.18	0.09	0.73	0.56	1.96	8.77	0.03	0.26	0.24	2.31
PCB 81	0.05	0.03	0.09	0.05	0.14	1.02	0.02	0.09	0.02	0.18
PCB 105	0.28	0.21	0.98	0.41	3.32	10.78	0.06	0.69	0.63	1.84
PCB 114	0.04	0.03	0.12	0.05	0.20	1.15	0.01	0.07	0.08	0.22
PCB 118	0.57	0.35	2.51	1.02	6.78	30.1	0.16	1.21	1.38	5.06
PCB 123	0.04	-	0.07	0.03	0.04	0.61	0.04	0.04	0.04	0.12
PCB 126	0.13	0.10	0.09	0.06	0.89	0.96	0.05	0.29	0.03	0.20
PCB 156	0.16	0.11	0.26	0.11	1.71	3.13	0.02	0.33	0.17	0.56
PCB 157	0.08	0.02	0.07	0.03	0.33	0.67	0.07	0.11	0.03	0.12
PCB 167	0.07	0.05	0.12	0.03	0.57	1.34	0.01	0.11	0.08	0.17
PCB 169	0.08	0.02	0.02	0.02	0.42	0.05	0.07	0.11	0.01	0.04
PCB 170	0.41	0.21	0.66	0.36	4.86	7.87	0.11	0.65	0.26	1.70
PCB 180	0.85	0.44	1.64	0.85	10.18	19.67	0.21	1.41	0.85	4.18
PCB 189	0.11	0.05	0.03	0.02	0.84	0.17	0.04	0.17	0.02	0.06
PCB 28	1.64	1.60	39.72	79.42	19.69	476.68	0.40	4.52	8.05	288.9
PCB 52	0.63	0.42	14.87	22.22	7.53	178.49	0.24	1.79	5.20	178.5
PCB 101	0.46	0.12	5.44	3.89	5.54	65.29	0.25	0.69	2.76	65.29
PCB 138	0.72	0.40	2.77	0.99	8.68	33.23	0.24	1.43	2.01	33.23
PCB 153	0.86	0.40	4.09	1.82	10.35	49.1	0.33	1.54	9.29	9.29
Total PCB					84.05	889.1				

Ave.:Average, SD:standard deviation, n:12 measurements
Total Particle and Total Gas Phase: Sum of the each month for one-year (May 2011- Apr. 2012) measurements

Average particle and gas phase concentrations were detected to be 84.05±5.16 pg/m^3 and 889.1±112.25 pg/m^3, respectively. Among the congeners, the highest concentration value in particle phase was detected to be 4.52 pg/m^3 for PCB#28 (October measurement) while the lowest one was detected to be 0.01 pg/m^3 for PCB#114 (September measurement) and PCB#167 (December measurement).

Similarly, the lowest gas-phase concentration was recorded at 0.01 pg/m³ for PCB#169, while the highest was 288.9 pg/m³ for PCB#28. The measured PCB#28 concentration was

288.9 pg/m^3 in April. Concentrations of PCB28 varied between 7.226 pg/m^3 (August measurement) and 51.72 pg/m^3 (July measurement) except April. There are ongoing serious concerns about the spread of PCBs in the environment, primarily due to their re-volatilization from sites where they have been stored or disposed of, as well as from the incineration of materials containing PCBs (Trinh and Chang, 2018). This unordinary case can be explained by a fire in a textile factory near the sampling point during sampling in April. Prevailing wind direction (SSW) during this sampling period confirmed the situation. In addition, combustion of PCB-containing electrical-electronic devices, other complex compounds and various chemicals used in the processes of textile industry are all considered to be other important causes of high PCB concentrations during fire at textile factory.

PCB emissions occur in industrial production, combustion of PCB-containing materials and other thermal processes at high temperatures (Aries, Anderson, Ordsmith, Hall and Fisher, 2004; Choi, Baek and Chang, 2008). It has been reported that combustion of hazardous and municipal wastes containing carbon causes formation and emission of PCB compounds (Alcock, Sweetman, Juan and Jones., 2000; Bergman, Hagman, Jacobsson, Jansson and Ahlman, 1984; Brown and Ganey, 1995). Moreover, distribution of PCB congeners varies greatly depending on the conditions of incineration. For example, some combustion conditions support formation of lower chlorinated PCB congeners (Brown and Ganey, 1995). Especially, less chlorinated PCB congeners have long been used in many commercial mixtures worldwide (Frignani, Bellucci, Carraro and Raccanelli, 2001). Gas phase concentrations of lower chlorinated PCB conegeners (3CB: 288.9 pg/m^3 4CB: 84.03 pg/m^3) during April 2012 sampling period were higher than other months. The cumulative concentrations for 3CBs and 4CBs homologue groups during whole sampling period except April were 197.78 pg/m^3 and 94.46 pg/m^3, respectively. Therefore, fire at the textile factory was thought to affect sampling area considering both prevailing wind direction and distribution of PCB congeners. Contributions of gas and particle phases to total PCB concentration were determined to be 91.4% and 8.6%, respectively.

3.2. Beşiktaş Sampling Site

Beşiktaş sampling point is surrounded by main roads having high traffic density together with very crowded residential area and commercial enterprises. Total PCB concentrations ranged from 22.77 pg/m^3 to 87.63 pg/m^3 and average concentration was determined to be 52.90 pg/m^3. Average concentrations of each PCB congener in particle and gas phases were shown in Table 3 (Çelikten, 2013). Average particle phase concentrations of PCB congeners ranged from 0.02 pg/m^3 to 1.53 pg/m^3 while gas phase concentrations ranged from 0.07 pg/m^3 to 17.69 pg/m^3.

PCB congeners were not detected in particle phase in some months during one-year campaign. All PCB congeners except PCB#169 were detected usually in all months. At this sampling point, distribution of percentage for 3CBs, 4CBs, 5CBs, 6CBs and 7CBs homologue groups during whole sampling period at particle phase were 23%, 10%, 21%, 29% and 18% respectively. This distribution for gas phase were 38% (3CBs), 20% (4CBs), 19% (5CBs), 17% (6CBs) and 5% (7CBs). Average concentrations were detected to be 74.81±4.96 pg/m^3 and 559.83±53.62 pg/m^3 for particle and gas phases, respectively. The lowest concentration in particle phase was detected to be 0.01 pg/m^3 for PCB#114, PCB#126 and PCB#189 congeners, while the highest concentration was detected for PCB#28 as 6.65 pg/m^3. Similar to particle phase, the highest concentration was detected for PCB#28 as 36.10 pg/m^3 while the lowest value was detected to be 0.01 pg/m^3 for PCB81 and PCB#189 congeners in gas phase. 88.2% of total PCB congeners were appeared in gas phase in Beşiktaş region.

Table 3. Explanatory statistics of PCB results measured at Beşiktaş

PCB Congeners	Particle Phase (pg/m³)		Gas Phase (pg/m³)		Total Particle Phase (pg/m³)	Total Gas Phase (pg/m³)	Lowest Particle Phase (pg/m³)	Highest Particle Phase (pg/m³)	Lowest Gas Phase (pg/m³)	Highest Gas Phase (pg/m³)
	Ave.	SD	Ave.	SD						
PCB 77	0.14	0.12	0.43	0.21	1.36	5.12	0.03	0.27	0.23	0.82
PCB 81	0.02	-	0.05	0.02	0.02	0.32	0.02	0.02	0.01	0.07
PCB 105	0.23	0.11	0.88	0.25	2.53	10.51	0.06	0.28	0.62	1.32
PCB 114	0.02	0.03	0.11	0.07	0.05	1.06	0.01	0.04	0.05	0.14
PCB 118	0.49	0.19	3.22	3.11	5.84	38.60	0.26	0.84	1.38	12.82
PCB 123	0.09	0.10	0.07	0.03	0.18	0.65	0.02	0.16	0.04	0.09
PCB 126	0.10	0.06	0.08	0.07	0.6	0.48	0.01	0.19	0.02	0.18
PCB 156	0.11	0.07	0.28	0.12	1.11	3.36	0.04	0.19	0.15	0.56
PCB 157	0.07	0.02	0.07	0.02	0.2	0.53	0.05	0.08	0.03	0.10
PCB 167	0.04	0.04	0.14	0.07	0.34	1.36	0.01	0.12	0.09	0.19
PCB 169	0.08	0.06	-	-	0.25	-	0.04	0.15	-	-
PCB 170	0.33	0.21	0.69	0.37	3.33	8.30	0.10	0.77	0.26	1.70
PCB 180	0.78	0.38	1.72	1.03	9.39	20.70	0.26	1.68	0.37	4.49
PCB 189	0.08	0.05	0.04	0.02	0.34	0.21	0.01	0.13	0.01	0.07
PCB 28	1.53	2.06	17.69	11	18.34	212	0.35	6.65	4.08	36.10
PCB 52	0.52	0.29	8.99	4.8	6.28	107.88	0.21	1.26	3.20	18.34
PCB 101	0.47	0.14	4.74	1.37	5.21	56.84	0.24	0.63	3.31	6.34
PCB 138	0.71	0.38	3.18	1.37	8.58	38.16	0.24	1.26	1.75	6.81
PCB 153	0.91	0.41	4.48	1.89	10.86	53.75	0.37	1.47	3.23	9.75
Total PCB					74.81	559.83				

Ave.:Average, SD:standard deviation, n:12 measurements
Total Particle and Total Gas Phase: Sum of the each month for one-year (May 2011- Apr. 2012) measurements

3.3. Fenertepe Sampling Site

Fenertepe sampling point is surrounded by large forested areas so that this point was chosen to represent the background concentration of PCBs in the atmosphere of Istanbul. Monthly PCB concentrations were determined to range from 20.85pg/m^3 to 86.04 pg/m^3 with the average of 33.35 pg/m^3. Average concentrations of each congener in particle and gas phases were shown in Table 4 (Çelikten, 2013). At this sampling point, distribution of percentage for 3CBs, 4CBs, 5CBs, 6CBs and 7CBs homologue groups during whole sampling period at particle phase were 27%, 12%, 18%, 25% and 18% respectively. This distribution for gas phase were 38% (3CBs), 20% (4CBs), 18% (5CBs), 18% (6CBs) and 7% (7CBs). Average particle phase concentrations of PCB congeners showed variation ranging from 0.02 pg/m^3 to 1.19 pg/m^3, while average gas phase concentration varied from 0.04 pg/m^3 to 11.12 pg/m^3.

Average gas and particle phase concentrations of PCBs in this area were less than the other two sampling points. In addition, unlike other sampling points, a group of PCB congeners (PCB#81, PCB#123, PCB#126, PCB#157, PCB#167, PCB#169 and PCB#189) were not detected in particle phase and another group (PCB#81, PCB#123, PCB#157, PCB#169 and PCB#189) were not in gas phase in some months. Average concentrations for particle and gas phases were detected to be 15.20±1.68 pg/m^3 and 57.48±5.72 pg/m^3, respectively. PCB#126, PCB#157, PCB#167 and PCB#189 were determined as congeners having the lowest concentration (0.01 pg/m^3) in particle phase, while PCB#28 was detected as the most abundant

congener in both particle (4.10 pg/m^3) and gas (39.2 pg/m^3) phases. Lowest concentrations in gas phase were detected for PCB#126 and PCB#169 as 0.01 pg/m^3. 79.11% of total PCB concentration was detected in gas phase in this sampling point.

Table 4. Explanatory statistics of PCB results measured at Fenertepe

PCB Congeners	Particle Phase (pg/m^3)		Gas Phase (pg/m^3)		Total Particle Phase (pg/m^3)	Total Gas Phase (pg/m^3)	Lowest Particle Phase (pg/m^3)	Highest Particle Phase (pg/m^3)	Lowest Gas Phase (pg/m^3)	Highest Gas Phase (pg/m^3)
	Ave.	SD	Ave.	SD						
PCB 77	0.10	0.07	0.32	0.20	0.98	3.86	0.02	0.19	0.21	0.93
PCB 81	-	-	0.07	0.07	-	0.55	-	-	0.03	0.23
PCB 105	0.13	0.07	0.64	0.21	1.48	7.67	0.05	0.26	0.46	1.24
PCB 114	0.02	-	0.07	0.03	0.02	0.67	0.02	0.02	0.05	0.09
PCB 118	0.27	0.13	1.46	0.55	3.24	17.47	0.07	0.38	1.04	3.07
PCB 123	-	-	0.06	0.03	-	0.39	-	-	0.03	0.12
PCB 126	0.04	0.03	0.05	0.02	0.21	0.41	0.01	0.08	0.01	0.07
PCB 156	0.09	0.06	0.21	0.08	0.68	2.51	0.02	0.19	0.12	0.36
PCB 157	0.03	0.02	0.04	0.02	0.18	0.35	0.01	0.05	0.02	0.07
PCB 167	0.03	0.02	0.10	0.05	0.17	1.04	0.01	0.06	0.06	0.17
PCB 169	0.04	0.01	0.04	0.03	0.07	0.12	0.03	0.04	0.01	0.06
PCB 170	0.22	0.10	0.53	0.29	2.62	6.33	0.11	0.38	0.20	1.16
PCB 180	0.49	0.23	1.27	0.78	5.41	15.29	0.21	0.98	0.18	3.27
PCB 189	0.07	0.02	0.12	0.23	0.14	0.82	0.01	0.08	0.01	0.64
PCB 28	1.19	1.63	11.12	9.91	14.28	133.5	0.25	4.10	3.51	39.2
PCB 52	0.42	0.21	5.38	3.41	4.98	64.59	0.15	0.86	2.53	15
PCB 101	0.33	0.12	2.96	0.94	3.64	35.58	0.13	0.52	2.22	5.5
PCB 138	0.36	0.16	1.8	0.81	4.37	21.65	0.05	0.67	1	3.29
PCB 153	0.54	0.24	3.2	1.46	6.48	38.45	0.22	1.14	1.26	6.44
Total PCB					15.2	57.48				

Ave.:Average, SD:standard deviation, n:12 measurements
Total Particle and Total Gas Phase:Sum of the each month for one-year (May 2011- Apr. 2012) measurements

Gas/particle phase fractionation of PCBs has been studied in the literature. For example, gas phase percentage of PCB compounds were detected to be 97% by Gambaro et.al. (2004) in Venice Lagoon (Italy), 95% by Taşdemir et.al. (2004a) in Chicago (the USA) and 90% by Yeo et. al. (2003a) in South Korea. In this study, PCBs have the tendency being in gas phase as in accordance with the literature (ATSDR, 2000). The organic matter content of atmospheric particles plays a crucial role in the transport of SVOCs between the gas and particle phases (Falconer and Harner, 2000; Harner and Bidleman, 1998). Therefore, it was considered that percentages of gas and particle phases reflect different sources among the sampling locations.

3.4. Seasonal Variation of PCB Concentrations

PCB concentrations in the sampling locations were examined in seasonal periods since concentrations of PCB congeners exhibit variation according to meteorological conditions such as temperature, prevailing wind direction and wind velocity. Seasonal concentrations were also evaluated in gas and particle phases at each sampling location. Fig. 2 shows seasonal

concentrations of PCB congeners in gas and particle phases at each sampling location (Çelikten, 2013).

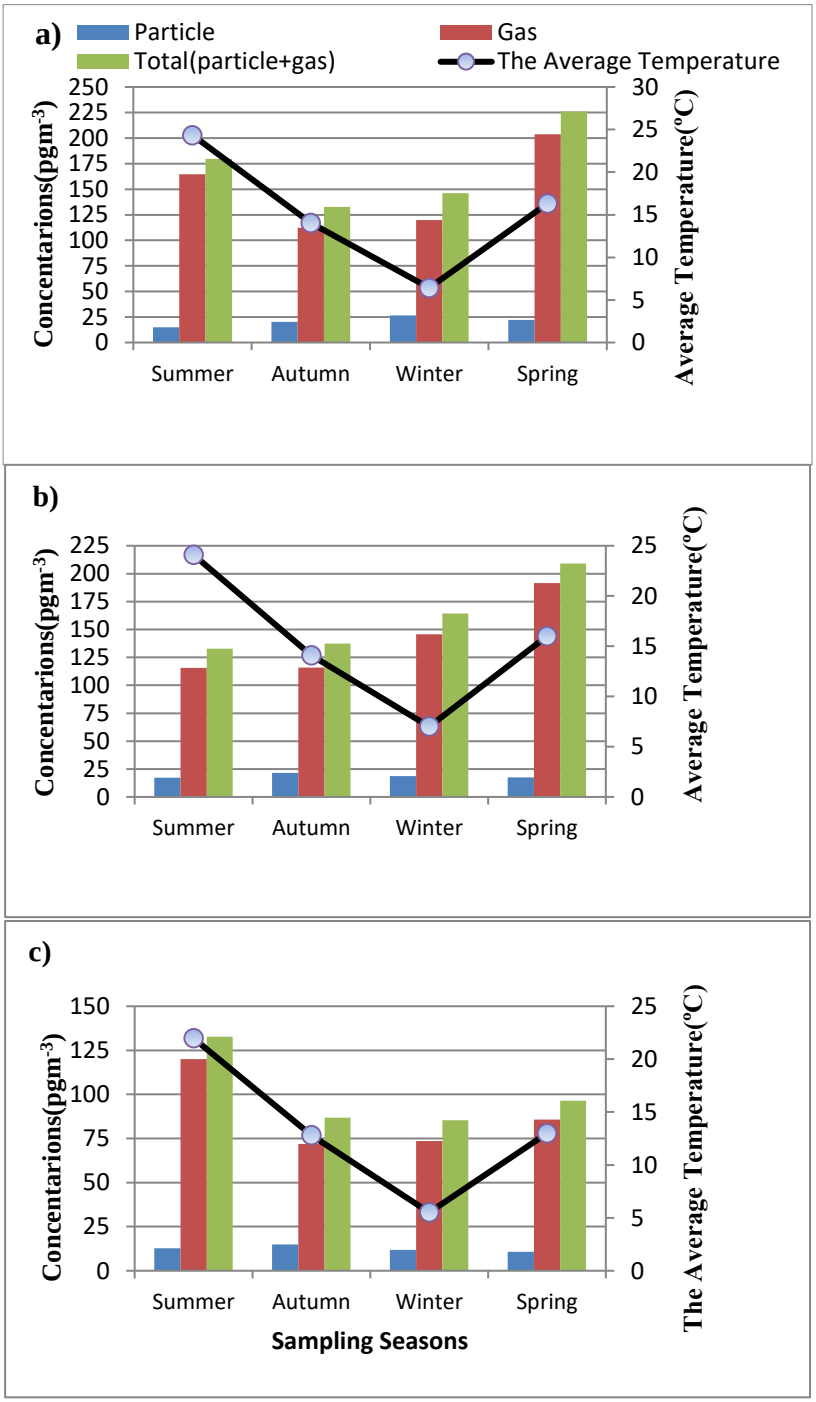

Figure 2. Seasonal PCB concentrations at a) Davutpaşa b) Beşiktaş c) Fenertepe sampling sites

Previous studies showed varying PCB concentrations depending on varying source profiles and seasonal conditions. (Mandalakis, Tsapakis, Tsoga and Staphanou, 2002; Kurokawa, Matsueda

Nakamura, Takada and Fukamachi,1996; Batterman, Chernyak, Gouden, Hayes, Robins and Chetty, 2009). Relatively high concentrations were detected during warm summer and

spring months at all sampling locations. Increasing rate of evaporation of PCBs may be the apparent reason for such trends (Carlson and Hites, 2005; Yeo, Choi, Chun, and Sunwoo, 2004).

Seasonal concentration variations were detected to be 515 pg/m^3 for spring, 179.56 pg/m^3 for summer, 146.3 pg/m^3 for winter and 132.6 pg/m^3 for autumn at Davutpaşa; and 209.5 pg/m^3 for spring, 164.34 pg/m^3 for winter, 137.41 pg/m^3 for autumn and 132.7 pg/m^3 for summer at Beşiktaş. Total PCB concentrations exhibited seasonal variations depending on local sources and bahaviour of the atmospheric transport mechanisms. Total concentrations measured in winter and autumn seasons were higher than summer season at Beşiktaş, revealing no meaningful relation between PCB concentration and temperature. In addition, total PCB concentrations turned out to be close to each other in summer, autumn and winter seasons. On the other hand, total concentrations for spring season were detected to be 515 pg/m^3 and 209.5 pg/m^3 at Davutpaşa and Beşiktaş sampling points, respectively. Therefore, fire that took place in April of 2012 in the textile factory located very close to Davutpaşa sampling point was considered to be the important factor for the apparent difference in concentrations between sampling points during spring season of the year 2012. PCBs in liquid form have transported to aerosol form at high temperatures due to the fire in factory leading to high probability of being inhaled by humans around the sampling location.

Seasonal concentrations of PCBs varied as 132.71 pg/m^3 in summer, 96.41 pg/m^3 in spring, 86.74 pg/m^3 in autumn and 85.4 pg/m^3 in winter at Fenertepe sampling point which reflects semi-rural properties. A significant portion of PCBs are emitted from water treatment facilities, waste deposition and disposal facilities, hazardous waste deposition areas, iron-steel correctional facilities (such as scrap auto incineration) (USEPA,1996). Fenertepe sampling station is located near the composting/recycling facility, municipal solid waste landfill area together with medical and hazardous waste incineration facilities which are about 8 km NE and 12 km SE from the sampling point.

PCBs can be retained strongly in soil for a long time (Ockenden et.al., 2003) and they evaporate from soil into atmosphere (Alcock, Bacon et.al., 1996; Gouin, Thomas et.al., 2002). Previous studies showed that PCB concentrations in urban and industrial areas are higher than rural areas (Simcik, Franz, Zhang and Eisenreich, 1998; Gambaro, Manodorı, Moret, Capodaglıo and Cescon, 2004). In this study, concentrations in Fenertepe were lower than in other sampling points which reflect urban and industrial source characteristics.

In the study conducted in İzmir, PCB concentration was detected to be 3136 and 1371 pg m^{-3} for summer and winter seasons at industrial area while it was detected to be 314 and 847 pg m^{-3} at urban area (Çetin, Yatkın, Bayram ve Odabaşı, 2007). The total (gas+particle) PCB concentration was determined as 106 pg in the study conducted in the province of Konya located in the middle Anatolian region of Türkiye (Özcan and Aydın 2009). In a another study conducted in Bursa, total PCB concentration was reported as 570, 394, 412, and 316 pg m^{-3} for coastal, urban, semi rural and remote areas respectively (Cindoruk and Taşdemir 2010). The difference between PCB concentrations can be explained by the type of PCB being measured and regional differences. Atmospheric behaviour of PCBs may considerably be affected by the reactions of hydroxyl radicals in vapour phase which transform the PCBs into other species (Brubaker and Hites, 1998). The distribution of SVOCs in the atmosphere plays a crucial role in their transport and transformation (Pankow and Bidleman, 1992). Relationship between total PCB concentrations and PM (TSP) values were examined and shown in Fig. 3. Regression analysis were also performed between particle phase PCB concentrations and PM values for each sampling point and regression coefficients (R^2) were calculated to be 0.21, 0.15 and 0.02 for Davutpaşa, Beşiktaş and Fenertepe sampling points, respectively. These figures reflect no

statistically meaningful relationship between particle phase PCBs concentrations and PM values. This case may be explained by high gas phase concentrations of PCB compounds.

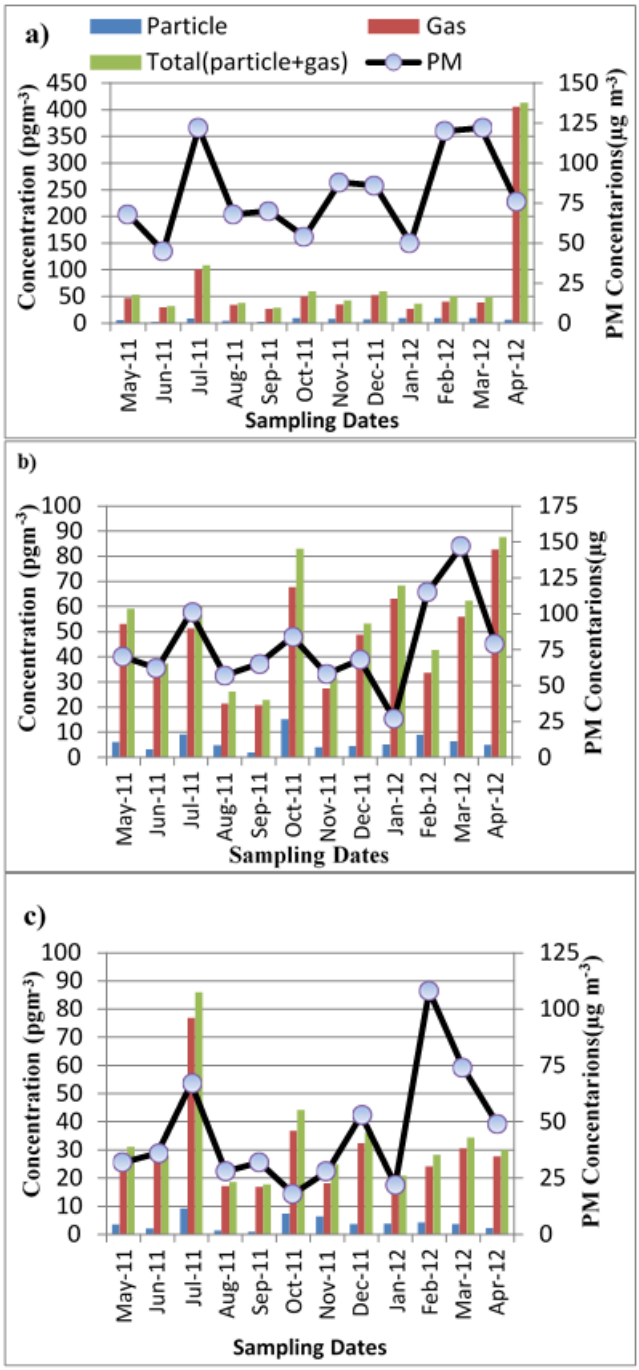

Figure 3. Relation between total PCBs and PM concentration at a)Davutpaşa b) Beşiktaş c) Fenertepe

3.5. Relationship Between Gas Phase PCB Concentrations and Temperature

It is well known that there is significant relationship between atmospheric concentrations of SVOCs and temperature. Previous studies showed that atmospheric concentration of SVOCs increase with increase in air temperature at several surfaces such as water (Bidleman and

McConnell, 1995), atmospheric particles (Yamasaki et.al., 1982), vegetation (Simonich and Hites, 1994) and snow (Stern, Halsall & et.al., 1997). This case is consistent with the liquid-vapor equilibrium theory explained by Clausius-Clapeyron Equation (Eq.1)

$$\ln P = \frac{m}{T} + b \quad (1)$$

where T (ºK) represents ambient air temperature and P (atm) represents partial pressure expressing the gas phase concentration of PCB congeners. Gas phase concentration of PCBs is associated with partial pressure and temperature as ln P vs (1/T) (Carlson and Hites, 2005; Lee and Jones, 1999). Slope (m) and intercept (b) give information about the atmospheric equilibrium and distance of emission sources (Sofuoğlu, Odabaşı, Taşdemir, Khalili and Holsen, 2001).

At equilibrium, the temperature dependence of a phase transition can be described by the Clausius-Clapeyron equation.

lnP = (-ΔHv/R)(1/T) + constant.
(2)

where P is gas phase partial pressure of SVOCs (atm), ΔHv is evaporation enthalpy (kJ/mol), R is the universal gas constant (0,0821 L atm mol^{-1} K^{-1}) and T is average atmospheric temperature (°K) at sampling period.

Gas phase concentration is expressed as partial pressure according to ideal gas equation in Eq.(2) so that it is inversely related to ambient air temperature corresponding this concentration. Slope (m) and intercept values were detected with Eq.(1) by using lineer relation form as ln P = m(1/T) + b. Clasius-Clapeyron curves were plotted for three sampling locations and they were used to understand the local weather cycles at surfaces. Slope values were obtained to be -2104.4 and -1913.9 for Davupaşa and Fenertepe sampling points, respectively (Figs.4 and 6) while, unlike these two sampling points, it was determined to be +1765.4 for Beşiktaş sampling point (Fig. 5).

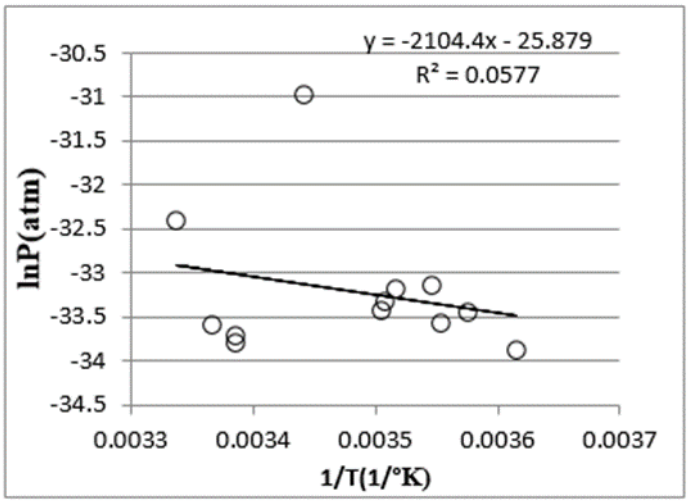

Figure 4. Clausius-Clapeyron graph for Davutpaşa sampling point

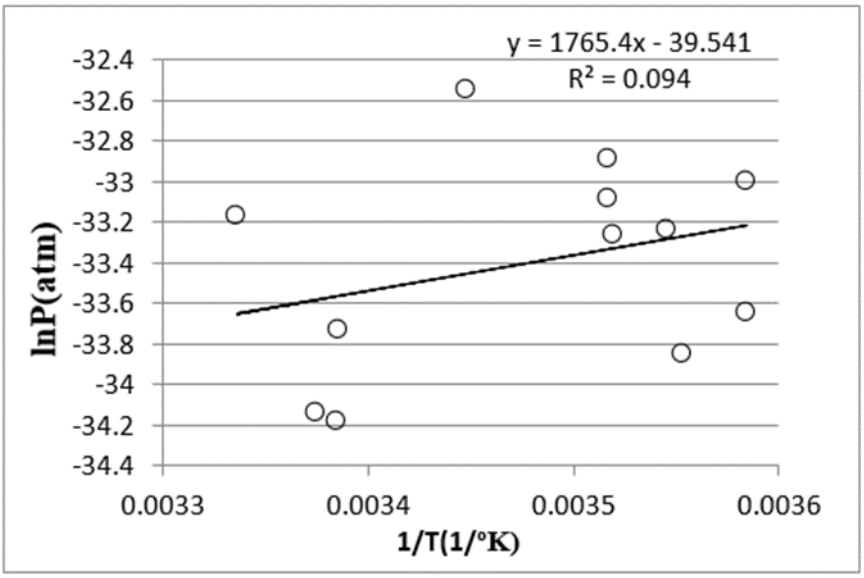

Figure 5. Clausius-Clapeyron graph for Beşiktaş sampling point

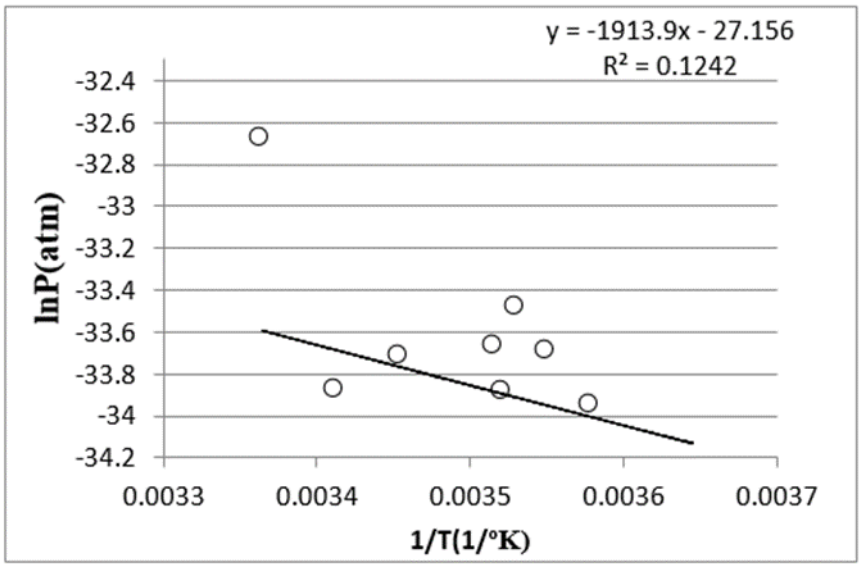

Figure 6. Clausius-Clapeyron graph for Fenertepe sampling point

The partial relationship was found between temperature and PCB congeners at Davutpaşa and Fenertepe sampling points. Reactions of atmospheric OH^- radicals increase with increasing atmospheric temperature (Anderson and Hites, 1996). This case shows that degradation of PCB congeners having higher volatility with OH radicals is higher than other congeners at Davutpaşa sampling point.

Slope values for PCBs were detected to be generally negative (-8503, -4650) in literature whereas positive slope value was detected for Beşiktaş sampling point in this study. This case implies that there is no meaningful relation between gas phase concentrations of PCB compounds and temperature at Beşiktaş sampling point. In addition, there are slope values similar to this study in the literature (Agrell, Okla, Larsson and Wania, 1999). These types of trends with their degrees of slopes are thought to show the importance of long distance transport against local transformations (Hoff, Brice and Halsall, 1998). Different slope values obtained from data of sampling points for PCB congeners reflect the importance of long distance

transportation between air masses and local surfaces. In addition, different slope values may thought to be the result of soil types of local surfaces, land use and vegetation.

4. CONCLUSION

The highest particle-phase concentration of total PCBs was recorded at the Davutpaşa sampling site, measuring 84.05±5.16 pg/m³, whereas the lowest concentration was observed at the Fenertepe semi-rural site, with 15.20±1.68 pg/m³. Similarly, for the gas phase, the highest concentration was detected at Davutpaşa (889.1±112.25 pg/m³), while the lowest was measured at Fenertepe (57.48±5.72 pg/m³). It is believed that a fire at a textile factory during the April 2012 sampling period significantly elevated PCB concentrations at the Davutpaşa site and altered the congener distribution profile. In this area, low molecular weight PCB congeners (tri- and tetra-chlorinated biphenyls, CB 3–4) contributed more significantly to the total PCB concentration compared to other congeners. This pattern suggests that low-chlorinated congeners may have been transported to the sampling site from nearby contaminated areas. The contribution of gas-phase PCBs to the total concentration was 91.4% at Davutpaşa, 88.2% at Beşiktaş, and 79.1% at Fenertepe, indicating a dominant presence of gaseous PCBs in the atmosphere. Overall, it was concluded that semi-volatile organic pollution in Istanbul's atmosphere is primarily driven by combustion-related emissions and aerosolized pollutants released from various sources.

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MICROPLASTICS AND THEIR EFFECTS IN AQUATIC ECOSYSTEMS

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ABSTRACT
Microplastics, defined as plastic particles ranging from 500 μm to 1 mm or up to 5 mm in size, have become a major environmental concern in aquatic environments. Primary microplastics (MPs) are deliberately produced tiny plastic particles that are incorporated into cosmetic items and industrial uses. Conversely, secondary plastic particles are formed when larger plastic debris undergoes fragmentation due to physical, chemical, and biological processes. Microplastics enter aquatic ecosystems through various pathways, including urban wastewater, river flows, and maritime activities, which are among the most significant sources. These microplastic fragments tend to build up in coastal zones and oceanic gyres. As plastic waste breaks down in the oceans over time, it gives rise to microplastics, which contribute to the gradual buildup of these pollutants within marine ecosystems. The effects of microplastics on marine organisms are a growing area of research. Many marine species, including plankton, fish, and crustaceans, can inadvertently ingest microplastics. This may result in obstructions in the digestive tract, decreased nutrient uptake, and other health-related issues. Furthermore, toxic chemicals can adhere to the surfaces of microplastics, allowing these harmful substances to enter the food chain and accumulate in larger organisms. Over time, processes such as bioaccumulation and biomagnification can exacerbate the impact of these toxins, posing serious threats to marine ecosystems and beyond. The presence of microplastics in aquatic environments is a multifaceted issue with environmental, economic, and social implications. Addressing this global challenge requires comprehensive solutions, including reducing plastic consumption, improving waste management systems, and developing cleaner production processes to minimize microplastic release. Advancing scientific research and strengthening global cooperation will be essential in reducing the long-term impacts of microplastic pollution on the world's aquatic ecosystems.
Keywords: Microplastic (MP) Pollution, Bioaccumulation, Ecosystem Health, Toxic Effects

1. GİRİŞ

With the creation of Bakelite in 1907, the first synthetic plastic, the evolution of low-cost manufacturing methods allowed for the mass production of lightweight, durable, and chemically inert plastics by the 1940s (Cole, Lindeque, Halsband and Galloway, 2011). Since the 1960s, global plastic production has grown at an average annual rate of about 8.7%, turning plastics into a dominant industry on a global scale (Smith, Love and Rochman, 2018). Due to their qualities, synthetic polymers have replaced many naturally derived materials in modern society (Lebreton & Andrady, 2019). Today, plastics have become an indispensable part of modern life and are widely used in industrial and consumer applications due to their durability, lightness and low cost.

The process that started with the first reports of plastic waste in the oceans in the 1970s (Cole, Lindeque, Halsband and Galloway, 2011) and the scientific interest in microplastics in recent years has made this topic an important area of research due to the widespread presence of these pollutants in seas and oceans (Wootton et al., 2024). Microplastics can consist of primary microplastics [MPs] from direct production (small synthetic beads in cosmetic and hygiene products) (Fendall & Sewell, 2009) or secondary MPs that occur as a result of the breakdown of larger plastic waste during product use or due to weathering of litter (Andrady, 2017). Microplastics, formed through the buildup and breakdown of plastic waste, particularly in aquatic environments, vary in size, with particles measuring less than 5 mm (Smith, Love and Rochman, 2018) to several μm (Andrady, 2017), and have become an increasing environmental problem.

Microplastic contamination in aquatic environments has become a major focus of scientific research in recent years. Microplastics have been detected throughout the water column—from surface waters (Zbyszewski & Corcoran, 2011; Despasari, Andarani, Priyambada and Inoue, 2023) to seas, oceans, lakes, rivers, and marine sediments (Thompson, Olsen, Mitchell et al., 2004; Isobe, Uchiyama-Matsumoto, Uchida and Tokai, 2017; Hale, Seeley, La Guardia, Mai and Zeng, 2020). The increasing use of plastics that pollute groundwater, surface waters, and marine environments, combined with the accumulation of plastic in surface waters, disrupts the chemical balance of aquatic ecosystems (Rajesh & Nagalakshmi, 2020). Due to their large surface area, microplastics can absorb waterborne pollutants—such as heavy metals and persistent organic pollutants (POPs)—and transfer these harmful substances to aquatic organisms (Andrady, 2011). Furthermore, the small size and diverse shapes of microplastics make them easily ingestible by many aquatic species, which often mistake them for food (Smith, Love and Rochman, 2018). Various marine organisms, including mussels, oysters, shrimp, and fish, can ingest these microplastics, allowing them to enter the human food chain through seafood consumption (Wu, Yang and Criddle, 2017). This highlights the far-reaching impact of microplastic pollution—not only posing serious risks to aquatic life and ecosystem integrity but also threatening human health through the food chain.

The presence and effects of microplastics in aquatic ecosystems is a complex problem with not only environmental but also economic and social dimensions. Therefore, understanding the sources, distribution, effects on ecosystems and potential solutions of microplastic pollution is of great importance for the protection of sustainable aquatic ecosystems. This research focuses on analyzing the current situation, sources, and consequences of microplastic pollution in aquatic ecosystems, alongside the solutions proposed to tackle this challenge. Learning more about the environmental behavior, biological interactions and long-term consequences of microplastics will be an important step towards developing effective solutions against this global problem.

2. RESEARCH AND FINDINGS

2.1. Structure and Dimensions of Microplastics

Plastics, which consist of long-chain monomers, have higher molecular mass and lower density; are an ideal packaging material due to their low cost, oxygen and moisture barrier properties, biological rigidity and lightness (Despasari, Andarani, Priyambada and Inoue, 2023). However, during their production, plastics are treated with thousands of different additives, such as flame retardants, colorants, antimicrobial substances, heat stabilizers, UV protectants, fillers, and fire retardants like polybrominated diphenyl ethers (PBDEs), in order to enhance specific properties. (EFSA, 2016; Lithner, 2011).

The term ‘‘microplastics’’ was first used to describe microscopic pieces of plastic that accumulate in marine sediments and the water column in European waters (Thompson, Olsen, Mitchell et al., 2004). Intentionally produced microplastics are referred to as primary microplastics and include microbeads in personal care products and industrial abrasives for delicate surfaces (Hale, Seeley, La Guardia, Mai and Zeng, 2020). Microbeads, with a size range of 10 to 500 μm (Wu, Yang and Criddle, 2017), are applied in various industries, including cleaning products, paints, coatings, drilling fluids for oil and gas operations, and the production of precursor resins and pellets used in plastic manufacturing (Hale, Seeley, La Guardia, Mai and Zeng, 2020). Secondary MPs, which are much more abundant in the oceans, are typically derived from the breakdown of larger plastic waste, either during product use or due to weathering of litter (Barnes, Galgani, Thompson and Barlaz, 2009). Small pieces of plastic have now become a near-permanent part of the natural environment as “microplastics”, spread from oceans to estuaries, from freshwater bodies to distant polar ice caps (Andrady, 2017).

Microplastics are diverse in terms of their chemical structure, physical characteristics, size, texture, and shape (Hale, Seeley, La Guardia, Mai and Zeng, 2020). To gain a comprehensive understanding of the fate and effects of microplastics in the environment, it is essential to measure all their properties in detail, ranging from size to chemical composition. As per the Joint Expert Group on Scientific Aspects of Marine Environmental Protection (GESAMP) 2015, the classification of plastic waste is detailed in Table 1.

Tablo 1. Classification of plastic waste in the environment according to GESAMP (Andrady, 2017).

Class	Size range of GESAMP	Scanning
Macroplastics	1000-25 mm	Without the aid of a microscope
Mesoplastics	25 mm-1 mm	Without the aid of a microscope or optical microscope
Microplastics	1 mm - 1 μm	Stereo mikroskop, FTIR, SEM
Nanoplastics	**< 0.001 μm**	**Mikro-FTIR spektroskopi Stereo mikroskop and ATR-FTIR**

2.2. Microplastics in Aquatic Ecosystems

In recent years, the worldwide demand for plastics has rapidly increased, driven by their adaptability, lightweight nature, durability, and the ability to be transparent, which makes them a perfect choice for various uses across many industries. (Andrady, 2011). The sources of terrestrial microplastics are diverse, including landfills, wastewater treatment plants, industrial

facilities (such as plastic production plants), plastic agricultural mulches, polymer paints, surface coatings, and wear from vehicle tires (Chae & An, 2018). These plastic particles are carried to water bodies through atmospheric transport and are discharged into the environment. Moreover, plastics can directly enter surface waters through activities such as fishing, aquaculture, intentional dumping from vessels, and debris from storms (Hale, Seeley, La Guardia, Mai and Zeng, 2020). Fishing gear, including nets, lines, buoys, and traps, often incorporates plastic and synthetic fibers. Although these materials are built to endure harsh environmental conditions, they deteriorate over time, gradually breaking down and moving into aquatic ecosystems (Hale, Seeley, La Guardia, Mai and Zeng, 2020).

In recent years, plastic waste has emerged as a significant environmental issue, contributing to widespread marine pollution. The presence of microscopic plastic particles in the oceans and the increasing trend in their numbers began to be documented in the early 2000s, and since then, global concerns about the problems caused by end-of-life plastics have rapidly increased (Shim and Thomposon, 2015). Microplastics (MPs) have become a pollutant that spreads to every corner of the oceans, posing a significant risk to marine life ecosystem and encouraging biological and ecological research to focus on this area (Andrady, 2017). Marine plastic wastes, especially microplastics with a high surface area to volume ratio, are prone to exposure to many waterborne pollutants such as dissolved metals, endocrine disrupting chemicals, and hydrophobic organic pollutants (HOCs), also known as persistent organic pollutants (POPs), in aquatic environments (Cole, Lindeque, Halsband and Galloway, 2011). Persistent organic pollutants (POPs) present in very low concentrations in seawater are adsorbed by meso- and microplastics through partitioning. The hydrophobic structure of POPs facilitates the accumulation of these pollutants in plastic waste at several orders of magnitude higher concentrations compared to seawater (Andrady, 2011). Persistent organic pollutants (POPs), including polychlorinated biphenyls (PCBs), polyaromatic hydrocarbons (PAHs), and organochlorine pesticides (such as DDT and DDE), are stable, lipophilic compounds that accumulate on hydrophobic plastic surfaces (Cole, Lindeque, Halsband and Galloway, 2011). POPs adsorbed by MPs present in seawater enter the marine food web, making them a potential source of ingestion (Bakir, Rowland and Thompson, 2012). When ingested by small organisms, chemically loaded microplastics may be transported upwards in the food pyramid and affect predators at higher trophic levels (Andrady, 2017).

Microplastics in ocean and marine environments are generally present as pellets, particles, or fibers, consisting of various types of polymers (Smith, Love and Rochman, 2018). Some of these polymers are denser than seawater, causing them to sink to the ocean floor. Examples include polyamide, polyester, polyvinyl chloride (PVC), and acrylic. On the other hand, lighter polymers such as polyethylene, polypropylene, and polystyrene tend to float on the surface of the water (Smith, Love and Rochman, 2018). The five most prevalent commercial thermoplastics commonly found in microplastics across oceans, seas, lakes, rivers, and estuaries are polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), polystyrene (PS), and polyethylene terephthalate (PET) (Wu, Yang and Criddle, 2017; Andrady, 2017; Hale, Seeley, La Guardia, Mai and Zeng, 2020). Table 2 shows the plastic classes and their typical properties frequently encountered in the marine environment (Wu, Yang and Criddle, 2017; Andrady, 2011).

Tablo 2. Main types of plastic found in the seas.

Category of Plastics	Molecular Formula	Specific Gravity	Production Percentage (%)	Materials and Typical Sources
Low density polyethylene [LDPE]	$(C_2H_4)_n$	0.91–0.93	21	Polyethylene bags/ Multi-pack can rings/ Plastic containers/ Fishing meshes/ Drinking straws
High density polyethylene [HDPE]	$(C_2H_4)_n$	0.94	17	Juice and milk packaging
Polypropylene [PP]	$(C_3H_6)_n$	0.85–0.83	24	Twine or cord/Cap lids/ Fishing nets or mesh
Polystyrene [PS]	$(C_8H_8)_n$	1.05	6	Disposable cutlery/,Takeout packaging
Thermoplastic Polyester [PET]	$(C_{10}H_8O_4)_n$	1.37	7	Plastic beverage bottles
Polyvinyl chloride [PVC]	$(C_2H_3Cl)_n$	1.38	19	Plastic wraps, beverage containers, drinking cups
Acetate of cellulose [CA]	$C_6H_7O_2(OH)_3$	1.28-1.32	-	Cigarette butts

A significant discovery in recent years is that tiny plastic particles, known as microplastics, are present in oceans across the globe (Barnes, Galgani, Thompson and Barlaz, 2009), and even in the remote waters of Antarctica (Zarfl and Matthies, 2010). These microplastics, a form of human-generated waste, have been gradually accumulating in marine environments for at least the past four decades (Andrady, 2011). In the Northern Hemisphere, large numbers of plastic pieces have been found in oceans as a result of plastic waste breaking down on beaches (Isobe, Uchiyama-Matsumoto, Uchida and Tokai, 2017). Many research studies in recent years have reported the accumulation of microplastics smaller than 5 mm in diameter in open oceans (Isobe, Uchiyama-Matsumoto, Uchida and Tokai, 2017) and marine areas near the coast (Isobe, Kubo, Tamura, Nakashima and Fujii, 2014), including Arctic polar waters. The transport of plastic pollution from rivers to coastal areas and oceans is also of critical importance. Lebreton et al. (2017) estimated that 1.15–2.41 million tons of plastic waste is transported to the oceans via rivers each year, while Schmidt et al. (2017) reported this amount as 0.47–2.75 million tons. Coastal water bodies (bays and estuaries) may show more plastic accumulation than rivers due to multiple pollution sources and complex circulation patterns. For example, while the microplastic concentration in the Beijiang River is 0.56 ± 0.45 particles/m³, this value varies between 0.11–68 particulates.m^{-3} in Xiangxi Bay (Hale, Seeley, La Guardia, Mai and Zeng, 2020). This rate increases to 4,137 particulates.m^{-3} in the Yangtze Estuary (Hale, Seeley, La Guardia, Mai and Zeng, 2020). Studies show that seasonal changes are important in microplastic transport. For example, the concentration of microplastics in Hong Kong waters near the Pearl River Estuary is higher during the rainy season (Hale, Seeley, La Guardia, Mai and Zeng, 2020). A one-year study in the Nakdong River revealed that 53–118 tons of microplastics were transported annually, with the highest concentration occurring during the rainy season (Hale, Seeley, La Guardia, Mai and Zeng, 2020).

2.3. Health Effects of Microplastics in Water

With the legal regulations in the 1970s, land and sea pollution began to be controlled, and in the 1980s, the UN developed agreements and deposit-refund systems regulating marine

pollution and transboundary movement of hazardous substances (Munhoz, Harkes, Beriot, Larreta and Basurko, 2022). The 1992 Helsinki Convention (HELCOM) defined any substance that could cause pollution when it entered the sea as harmful, and the UN Global Action Programme created action plans against land and sea pollution (Munhoz, Harkes, Beriot, Larreta and Basurko, 2022). While plastics were not initially specified in these regulations, agreements such as the Barcelona Convention, the Northwest Pacific Action Plan, the OSPAR Convention, and the revised Basel Convention, which now address microplastics, have been updated to tackle the issue of plastic pollution (Munhoz, Harkes, Beriot, Larreta and Basurko, 2022). Due to the current increasing pollution, reduction measures play an important role in combating microplastic pollution.

Non-polymeric substances, including chemical additives and residual monomers leaching from plastic polymers, can pose significant risks to both human health and the environment (Smith, Love and Rochman, 2018). As plastics degrade over time, their surface area-to-volume ratio increases, facilitating the leaching of these additives. The released chemicals can accumulate in the biological tissues of animals (Smith, Love and Rochman, 2018). When aquatic organisms consume microplastics, these particles can ultimately enter the human body via the food chain, posing potential health risks associated with microplastic contamination. Moreover, the tiny size of microplastics allows them to be easily absorbed by the soft tissues of organisms, which increases the danger to living creatures (Despasari, Andarani, Priyambada and Inoue, 2023). Seafood consumption represents one of the main pathways through which humans are exposed to microplastics. Furthermore, microorganisms that colonize the surface of ingested microplastics can act as carriers of harmful bacteria, leading to direct physiological consequences in marine life. These consequences include nutritional, toxicological, immune, and developmental impacts (Smith, Love and Rochman, 2018). Wright and Kelly (2017) suggested that ingesting microplastics could trigger inflammation, cell proliferation, and cell death (necrosis) in tissues, while also impairing immune cell function. The severity of the adverse effects from microplastic exposure depends on factors such as the nature of the toxic chemicals involved, the specifics of the exposure, individual vulnerability, and the measures taken to control hazards. Although the physical effects of microplastic buildup are less comprehensively understood compared to the way toxic substances are distributed and stored in the human body, initial research has raised considerable concerns. These effects include heightened inflammatory responses, toxicity related to the size of plastic particles, the transfer of chemicals adsorbed on plastic surfaces, and disruption of the intestinal microbiota (Wright & Kelly, 2017). Nanoplastics ingested orally are transported from the intestine into the bloodstream via specialized epithelial cells called M cells in the mucosa, where they eventually reach the liver and gallbladder through the lymphatic system (Bergmann, Gutow and Klages, 2015). Due to their size and hydrophobic nature, nanoplastics can cross the placenta and blood-brain barrier, potentially affecting the gastrointestinal tract and lungs, creating sites of harm (Smith, Love and Rochman, 2018). Studies have shown that nanoplastics are toxic to lung cells, liver cells, and brain cells in vitro. The systemic distribution of nanoparticles via the mouth can lead to various effects, including cardiopulmonary responses, changes in internal metabolic processes, genotoxicity, inflammatory reactions, oxidative stress, disruptions in nutrient absorption, alterations in the gut microbiota, and reproductive disorders **(**Smith, Love and Rochman, 2018**).**

3. CONCLUSION

Microplastics pose an escalating threat to aquatic ecosystems, representing a multifaceted issue with significant environmental, economic, and social implications. These tiny plastic

particles originate from both ınitial and subsequent sources, becoming particularly concentrated in oceans, seas, and rivers. The impact of microplastics on marine organisms can lead to severe consequences, which ultimately affect human health via the food chain. When consumed by marine life such as plankton, fish, and crustaceans, microplastics can obstruct the digestive system, impair nutrient absorption, and facilitate the transfer of harmful chemicals into the organisms. Research aimed at understanding the effects of microplastics on marine life and human health will be crucial in developing effective strategies for preventing and managing microplastic pollution. Addressing this issue calls for solutions such as policies to reduce plastic consumption, ımprovements in waste management strategies, and the development of production methods that are less damaging to the environment. Furthermore, fostering scientific research and strengthening international cooperation will be vital in mitigating the environmental impact of microplastics. In particular, gaining a deeper understanding of the behavior, biological interactions, and long-term effects of microplastics within aquatic ecosystems is essential for creating effective solutions to this global challenge.

To conclude, the issue of microplastic pollution carries considerable risks to the environment, public health, and economic stability. The solution to this problem will be possible by increasing individual awareness, reviewing industrial practices and implementing coordinated actions at the international level. Steps to protect aquatic ecosystems will ensure that cleaner and more sustainable water resources are left for future generations.

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EFFECTS OF TRIACONTANOL APPLICATIONS ON PELLET FERTILIZER CONTENT AND EFFICIENCY

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Abstract
Triacontanol is a natural 30-carbon primary alcohol with a straight chain structure that provides plant growth-stimulating activity. Tria is a natural plant growth regulator found in nature in plant origin and animal origin in the structure of beeswax. The compound's molecular structure, whose synonyms are medical alcohol, miraculin, and myristyl alcohol, is CH3-(CH2)29-OH and is a natural substance found in living organisms that promotes plant growth. Triacontanol encourages plant growth by increasing the amount of free amino acids, reducing sugars, photosynthetic activity, soluble protein, and growth. For this purpose, triacontanol was added to pellet fertilizer at different rates, and its effects on pellet quality and nutrient content were evaluated. Within the scope of the study, pellets were formed from sugar beet wastes, and triacontanol was added to each pellet at doses of 0, 1.0, 5.0, 10.0, and 20.0 µM. After the added samples were pelletized, the nutrient content of each pellet was determined. According to the results obtained, there was a significant change in the nutrient content of the pellet in response to the triacontanol application dose. According to the results of this study, it was determined that if triacontanol is applied to the soil with a carrier medium, it will significantly contribute to plant growth due to the positive effects it produces.
Keywords: Triacontanol, Pellet, Fertilizer

INTRODUCTION

In order for agricultural production to be sustainable and to achieve high levels of yield from the plants produced, the protection of soil properties and the development of ideal soil properties are among the important parameters. In addition, good fertilizer management has a very strategic position in order to obtain more yield from the unit area (Bayoumi and El-Demardash, 2008). The most preferred method for regulating many properties of the soil and ensuring sustainability for future generations is generally carried out by adding organic substances (Bender et al. 1998). At this point, while the crops of plants harvested in our country's lands are valued, plant residues left in the field are not utilized as waste. Plant residues can be utilized in different ways such as animal feed, compost, fertilizer and fuel. However, biomass residues not only provide benefits to energy production, but also can reduce inputs from an economic perspective for businesses that utilize plant residues, which is one of the most important points of sustainable agricultural management (Evcim et al. 2012). Sugar beet planting areas are quite large in our country and after the sugar beet is harvested, the head and leaf parts of the plant remain in the field. It is important to be able to evaluate the existing plant residues left in the field. The types of fertilizers that can be used by evaluating the residues vary. Recently, pellet fertilizers have become the most popular. Pellets have a small and cylindrical structure that resembles animal feeds. Pellet sizes are generally produced in 6 to 12 mm diameter and 10 - 30 mm length. The production of plant residue materials in smaller sizes under pressure is called pelleting (Küsek et al. 2015). Alemi et al. (2010) stated that while the production of fertilizers in pellet form ensures that the release is slow, at the same time, an increase in nutrient absorption is provided due to this management of the fertilizer. Therefore, pelleted fertilizers have created an alternative method that comes to the fore because they facilitate absorption at every stage of the plant's development process with the gradual and continuous release of elements (Reza-Bagheri et al. 2011). By pelletizing plant wastes, both more utilization of wastes and their use becomes easier. In order for the pelletized organic substances to have more effect, it is thought that different nutrients and naturally available substances can be added to the pellet production and the pellets can have more effect. One of the substances that can be added is triacontanol. TRIA, as a plant growth supporting substance, increases growth and development in plants even at low application levels (Naeem et al. 2012). Because when applied, it regulates yield and quality characteristics in plants such as plant biomass, chlorophyll pigments, nutrient element uptake, nitrate reductase activity (Naeem et al. 2009, 2019; Waqas et al. 2016; Zaid et al. 2019). At the same time, many research studies have reported that it positively affects the morphological parts of plants and therefore provides an increase in the vegetative parts of the plant (Kumaravelu et al. 2000; Naeem and Khan, 2005; Naeem et al. 2019).This research article was written because the plant residues remaining in sugar beet production areas can be turned into pellet fertilizer and TRIA can be added to these pellet fertilizers to make them more effective.

DEVELOPMENT

Effects of Triacontanol Applications on Plants

Triacontanol, isolated from alfalfa, is a saturated alcohol with a straight chain structure and a formula of 30 carbons, $CH_3(CH_2)_2sCH_2OH$ (Ries et al., 1977). It is naturally present in epicuticular waxes formed by many different plant species such as Croton californicus, Copernica cerifera, Medicago sativa, Jatropha curcas, Oryza sativa, Vaccinium ashei (Hufford and Oguntimein, 1978; Luzbetak et al. 1978; Lee et al. 1979; Freeman et al. 1979; Uchiyama and Ogasawara, 1981). Triacontanol has supported many plant species even under adverse

environmental conditions and helped to ensure that yield and quality parameters were minimally affected. Because TRIA can minimize or maximize stress responses due to the regulation of gene expression in plants (Perveen et al. 2017; Islam et al. 2020). Since it is a growth-promoting content even when applied at low doses, it increases plant growth and development (Naeem et al. 2012). In some cases such as heavy metal, salt content, temperature and water scarcity, which are soil and climate conditions, the plant is affected both physiologically and morphologically, and for these reasons, its productivity is affected (Morkunas et al. 2014; Ahanger et al. 2017, 2018; Egamberdieva et al. 2017). Many researchers have stated that TRIA plays a role in increasing the level of photosynthesis, nitrogen fixation amount, enzyme activation, free amino acid contents, reducing sugars and soluble protein amounts while promoting plant growth (Ries 1991; Ries et al. 1993; Nagoshi and Kawashima 1996; Borowski et al. 2000; Naeem et al. 2009; Aftab et al. 2010; Idrees et al. 2010; Naeem et al. 2010, Naeem et al. 2011).

Effects of Applıcation of Organıc Materıals as Pellets on Plants

Jayadi et al. (2023) applied phosphate-solubilizing microbes, organic pellet fertilizer and inorganic fertilization to corn plants and as a result, they determined that the applications in which the highest number of leaves was reached were obtained by applying organic pellets and inorganic fertilizers together. Kaniszewski et al. (2019) stated that the application of pellet fertilizers originating from red clover and alfalfa plants to the land where only compost fertilizer was applied for sustainable onion production increased the production amount in direct proportion to the application rates of fertilizers. Alagamba et al. (2025) determined that plants to which pellet fertilizers obtained from animal and plant wastes applied to corn plants showed more development than plants to which control and synthetic fertilizer were applied and they also stated that it can be used as an alternative fertilizer. In a study aiming to reduce synthetic fertilizer with fertilizer pellets in soilless environment, they came across the opinion that pellet applications positively affected plant shoot and growth rate compared to negative control (Liu et al. 2019).

CONCLUSION

Nowadays, fertilizer resources and their alternative use are of great importance. Because if we do not follow a sustainable agricultural policy, the soil and environment we will leave to future generations will be quite dirty or unhealthy. At this point, evaluating the materials we have and which have become unusable means turning garbage into gold. It is very important to evaluate the sugar beet waste mentioned above and to enrich the fertilizer obtained from this plant waste, which is evaluated and turned into pellets, with TRIA. If this study is carried out, it is thought that an alternative fertilizer, better utilization of plant waste and addition of TRIA to fertilizers will positively affect the yield and quality parameters of plants and will also protect soil health since it is an organic material.

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EFFECT OF TRIACONTANOL ON PLANT GROWTH

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Abstract
Triacontanol (Tria) is a low-dose, non-toxic plant growth regulator that promotes rapid protein synthesis. Triacontanol affects plant rooting, germination, flowering, stem and leaf growth, and early maturity. Tria is a natural plant growth regulator found in nature in plant origin and the beeswax of animal origin. Tria has been found to have various benefits on plants, such as doubling plant fresh weight in one year, realizing 3 years of growth in one growth period, and increasing the number, area, and thickness of leaves in the plant. Triacontanol has been chemically synthesized for its properties and benefits. TRIA can also be extracted with supercritical carbon dioxide from rice bran, sugarcane crude wax, and beeswax. The literature studies on the effects of Tria applications on plant development determined that Tria promoted seed germination, increased germination rate, cell division in plants, elongation and development of the plant, and increased plant growth by promoting plant root and stem development. In addition, by affecting many other plant growth factors, it causes improvements in plant resistance mechanisms to stress conditions. Triacontanol is of growing importance and great interest in agricultural applications due to its use as a plant biostimulant. This article evaluated the research results on the stimulant effects of triacontanol on plants and its applications.
Keywords: Triacontanol, Plant, Growth

INTRODUCTION

All plants produced under controlled conditions, except for the ones that continue their development, are faced with many adverse conditions that limit their development in the areas where they continue their development. Environmental factors are known as the basic components that affect plant morphology, physiology, metabolism, yield and developmental adventure. While plant development is positively affected in plant environments where environmental conditions are at optimum levels and at the same time there are organisms that benefit the plants, plant development is stressed in an environment where conditions are adverse and harmful pathogens are present. Stress in plants is defined as morphological and physiological differences that occur in plants due to biotic and abiotic factors in cases where temperature, drought, salinity, nutrient deficiency, heavy metal content and weed content are high, respectively (Willey, 2016; Sabagh et al. 2021a, 2021b).

In agricultural production, it is of great importance to minimize the stress that occurs in plants when environmental conditions are adverse and to research new methods that will be applied and developed to support stress management. Because today, with the sudden changes in climate and the increasing population, there is a need for more production in small areas and products with more tolerance to stress. New alternative ingredients to be used as plant growth regulators have begun to be investigated in order to increase the production amount and tolerance to stress conditions. Plant growth regulators are vital signal molecules that directly or indirectly affect the tolerance that will occur under abiotic stress conditions, as well as the regulations they provide at many stages of plants during their growth and development (Wani et al. 2016; Handa et al. 2018; Zaid and Mohammad 2018; Ahmad et al. 2018; Asgher et al. 2018; Ciura and Kruk 2018). According to the studies, Triacontanol, one of these plant growth regulator substances, has been found. Triacontanol, a plant growth regulator, is formed in waxes found in many plants such as alfalfa, rice, and soap tree (Hufford and Oguntimein, 1978; Luzbetak et al. 1978; Lee et al. 1979; Freeman et al. 1979; Uchiyama and Ogasawara, 1981). Triacontanol was first encountered in straw produced from alfalfa plants and is an alcohol naturally formed by plants that has effects on more than one physico-biochemical process in different plant species (Karam and Keramat, 2017). It is a growth promoter that increases plant growth when applied to plants at low concentrations (Naeem et al. 2009). When evaluated from an agricultural perspective, TRIAC is generally concerned with metabolic functions, plant growth, development and yield affected by these reasons, and the formation of responses to abiotic stress conditions that plants are exposed to. Apart from its role in stimulating plant genes and switching the plant to a defensive state. Triacontanol has been the focus of researchers in order to increase the yields under most abiotic stress conditions due to its stimulatory effects on water uptake and nutrition of plants, photosynthesis, enzyme activation, membrane stability and formation in genes (Perveen et al. 2012). As a highly effective growth regulator, it has been used in many plants for its positive effect on the growth of shoot and root organs due to its morphological features and to produce secondary metabolites (Rao et al. 1981). Moreover, it positively affects many vital physiological events such as volatile oil yield in some plants (Misra and Srivastava 1991; Khanam and Mohammad 2018), flowering of plants in a short time (He and Loh 2002), assimilation of nitrogen (Muthuchelian et al. 2001; Ertani et al. 2013), accumulation of antioxidants such as proline, glycine and beatine, and provides protection of plants by creating a defense system against stress due to environmental conditions (Ries and Stutte 1985; Borowski et al. 2000; Perveen et al. 2010, 2012a; Karam and Keramat 2017; Keramat et al. 2017; Khanam and Mohammad 2018). It has been stated that triacontanol not only combats stress on plants, but also increases plant development and the yield of the obtained crops. As a result of examining many different studies, data have been

obtained that TRIA applied to the root zone and plants as a spray from the leaves increases the development and yield of some vegetable and cereal species (Ries et al. 1977, 1978).

This research article was written about triacontanol, which can be obtained naturally as a plant growth regulator due to the many positive reasons mentioned above.

DEVELOPMENT

Properties of triacontanol

In the study conducted by Chibnall and his friends in 1933, they first determined triacontanol, known as a primary alcohol with a carbon content of 30, as a natural content of plants, also found in alfalfa. The chemical formula of TRIA is CH3(CH2)28 and its molecular weight is 438.8 g mol–1 (Sharma and Kapoor, 2023). Ries et al. (1977) first encountered triacontanol, known as a plant growth regulator, as a result of their study on alfalfa. However, it was determined that triacontanol, which is naturally found, is not only found in alfalfa but also in other plants. For example, when the studies carried out later were examined, evidence was given that TRIA was present in epicuticular waxes of many different plant species such as California croton, blueberry, bean, and kurka (Hufford and Oguntimein 1978; Luzbetak et al. 1978; Freeman et al. 1979; Lee et al. 1979). TRIA, known as a plant growth regulator, stimulates plant growth in plants applied at low density and provides an increase in growth rate (Naeem et al. 2012). In many different studies, it was determined that the effects of TRIA on the morphological parts of plants were very important and when the yield parameters were examined, it increased plant height, biomass, leaf amount and leaf width (Kumaravelu et al. 2000; Naeem and Khan, 2005; Naeem et al. 2019). While it affects yield parameters directly or indirectly, it increases the components that play an active role in transpiration rate, photosynthesis rate, nitrogen fixation, nutrient and water intake, amino acids, sugars and volatile oil amount, to name a few (Aftab et al. 2010; Aziz et al. 2013; Naeem et al. 2014). It has been determined that triacontanol affects the plant positively as a result of studies carried out both in optimum and minimum environmental conditions.

Effects of triacontanol applications on development

It has been reported that the application of TRIA applications to the root zone and leaf surface affects the growth of many vegetable and cereal species and therefore increases yields (Ries et al. 1978; Ries and Wert, 1977). Bhandari et al. (2021) applied triacontanol at different doses and times in their cabbage study and as a result, they reached the highest plant height and largest leaf length with triacontanol application at a dose of 1 ml L-1 on the 40th day. They found that the height, number of branches and dry weight of the plant increased fourfold compared to control plants with the application of 1 μM TRIA to poppy plants (Khan et al. 2007).

Effects of triacontanol applications on yield

TRIA is generally known to positively affect development and physicochemical properties, but it does not only affect these properties, but also increases the quality, content and yield level of the products (Naeem et al. 2009, 2010, 2011). Table 1 below shows the percentage yield increase of TRIA applications compared to the control in some studies without considering the stress conditions. Bhandari et al., (2021) determined that the yield was increased with 2 ml L-1, 1.5 ml L-1 and 1 ml L-1 application doses, respectively, thanks to the application of triacontanol to cabbage plants at different times and different doses. Mallick et

al. (2009) carried out tria applications on potato plants as follows: T2 – Triacontanol 95% @ 1 ml lit-1 water, T3 – Triacontanol 95% @ 0.5 ml lit-1 water, T4 – Triacontanol 95% @ 0.33 ml lit-1 water, T5 – Triacontanol 0.1% @ 0.5 ml lit-1 water, T6 – Triacontanol 0.05% @ 1 ml lit-1 water, T7 – Nitro benzene 20% @ 2.5 ml lit-1 water. Among the applications, the application dose that affected plant yield the most was 0.33 ml L-1. Baba et al. (2017) applied salicylic acid (1 mM and 2 mM) and triacontanol (5 µM, 10 µM) on strawberry plants. After the applications, it was determined that the highest concentrations of salicylic acid and triacontanol increased the yield the most, while this study determined that more yield could be obtained by applying triacontanol to strawberry plants at only 10 µM concentration.

Table 1. Some studies in which triacontanol application was performed.

Plant Species	**Triacontanol Application Doses**	**Most Effective Dose**	**Yield Increase Percentage Compared to Control**	**Reference**
Lahana	1 ml L^{-1}, 1.5 ml L^{-1}, 2 ml L^{-1}	2 ml L^{-1}	% 40.44	Bhandari et al. (2021)
Patates	1 ml L^{-1}, 0.5 ml L^{-1}, 0.33 ml L^{-1}	0.33 ml L^{-1}	%19.73	Mallick et al. (2009)
Çilek	5 µM, 10 µM	10 µM	% 21.19	Baba et al. (2017)

CONCLUSION

Triacontanol is a plant growth regulator that can regulate the physiological and biochemical stages of plants at this point where it affects yield and quality parameters in multiple plant species. It plays an important role in the defense mechanism of plants against weather changes caused by global warming, water shortages and environmental conditions that have become negatively affected by humans. It has been determined in literature studies that TRIA application increases yield and quality parameters when applied to plants from leaves. However, more research needs to be done to fully know the content of triacontanol in plants and to find the appropriate dose parameter for all plant species consumed.

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HAYVANSAL ATIKLARDAN ELDE EDİLEBİLECEK ENERJİ POTANSİYELİ (EDİRNE İLİ ÖRNEĞİ)

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Özet
Bu çalışmada, Edirne ilinin hayvan potansiyeli ele alınmış ve elde edilebilecek enerji miktarı belirlenmiştir. Edirne ilindeki büyükbaş, küçükbaş ve kanatlı atıklarından elde edilebilecek gübre miktarlarının biyogaz olarak değerlendirilmesi çalışması yapılmıştır. Büyükbaş, küçükbaş ve kanatlı hayvan verileri Türkiye İstatistik Enstitüsü'nden alınmıştır. Bu verilere göre 2023 yılı itibariyle il genelinde 142046 adet büyükbaş, 364855 adet küçükbaş ve 199810 adet kanatlı hayvan bulunduğu hesaplanmıştır. Hesaplanan atık miktarlarına göre, elde edilebilecek gübre miktarı büyükbaş hayvanda 511365,60 ton/yıl, küçükbaş hayvanda 255398,50 ton/yıl ve kanatlılarda ise 4395,82 ton/yıl olarak hesaplanmıştır. Hesaplanan gübre miktarlarına göre biyogaz üretim miktarı büyükbaş hayvanda 11250043,20 m^3/yıl, küçükbaş hayvanda 9875408,67 m^3/yıl ve kanatlılarda ise 228582,64 m^3/yıl olup, toplam elde edilebilecek enerjinin eşdeğer karşılıkları ise 100363962,18 kWh/yıl (361310,26 GJ/yıl) olarak hesaplanmıştır. İl genelinde hayvansal atıkların bir biyogaz tesisi ile enerjiye dönüştürülmesi mikro ve makro ekonomi açısından önem arz etmektedir.
Anahtar Kelimeler: Edirne, Biyogaz, Enerji, Hayvansal Atık

ENERGY POTENTIAL FROM ANIMAL WASTES (THE CASE OF EDIRNE PROVINCE)

Abstract
In this study, the livestock potential of the Province of Edirne has been analysed and the possible amount of energy to be acquired has been calculated. A study has been performed to assess the opportunities to use cattle, small cattle and poultry animals' fertilizers in Edirne as biogas. Data of cattle, small cattle and poultry animals has been taken from the Turkish Statistical Institute. According to these data, there are 142046 cattle, 364855 small cattle and 199810 poultry animals in the province as of 2023. Based on the calculated excrement values, the amount of fertilizer that can be possible acquired has been calculated as 511365,60 ton/year for cattle, 255398,50 ton/year for small cattle and 4395,82 ton/year for poultry animals. Based on the calculated fertilizer amounts, biogas production amount has been calculated as 11250043,20 m^3/year for cattle, 9875408,67 m^3/year for small cattle and 228582,64 m^3/year for poultry animals, while the corresponding values for the total energy has been calculated as 100363962,18 kWh/yıl (361310,26 GJ/yıl). In micro and macro economical terms, it is highly important to transform animal waste of the province into energy by a biogas facility.
Key Words: Edirne, Biogas, Energy, Animal waste

Giriş

Çağımızda en önemli sorunlardan biri enerjidir. Enerji ve üretiminin çevreyi etkilediği bilinmektedir. Çevreye etkisi enerjinin türüne bağlı olarak değişmektedir. Türkiye gibi ulusal gelirin büyük bir kısmını tarımdan sağlayan ülkeler, tarımsal atıkları ve diğer kaynaklarını en etkin bir biçimde kullanmak durumundadırlar (Taner ve ark, 2003). Organik atıkların havasız şartlarda fermantasyonu sonucunda elde edilen biyogaz, alternatif enerji kaynakları arasında önemli bir yere sahiptir. Biyogaz, gübrenin havasız şartlarda fermantasyonu ile elde edilebilir ve fermente olmuş gübre tarımda daha değerli bir kaynaktır. Gübrelerin biyogaz tesisinde kullanılmasıyla gübrelerde koku yok olmakta, hastalığa yol açabilecek mikroplar etkisiz hale gelmektedir (Akbulut ve Dikici, 2004). Biyogaz üretimi tarımsal atıklardan yararlanılarak yapılabileceği gibi endüstriyel atıklardan yararlanılarakta yapılabilmektedir. Kentsel atıkların ayrı ayrı toplanılması ve kanalizasyon atıklarının arıtma tesislerinde toplanılmasıyla önemli ölçüde biyogaz üretim imkânı vardır. Hayvan gübresinin tarımsal üretimde kullanılması, yakılarak enerjiye dönüştürülmesinden daha ekonomiktir. Hayvan gübresi, yapay gübrelere göre daha üstün özelliklere sahiptir. Toprağa bitki besin maddelerini sağlamasının yanında toprağın yapısını da iyileştirmektedir. Hayvan gübresinin yakılmasının önlenerek, tarım topraklarına kazandırılması, kırsal kesime bu enerjinin yerine ikame edeceği yeni bir enerjinin verilmesi ile mümkündür. Bu enerji, hayvan gübresinden elde edilebilecek olan biyogazdır (Afacan ve Kasap, 2009). Biyogaz üretim süreci, organik karbon içeren biyokütlenin (yağlar, karbonhidratlar ve proteinlerin maksimum oranlarda parçalanması) genel bileşimi biyogaz olarak anlaşılan metan, karbon dioksit ve bazı düşük oranda diğer gazlara dönüştürebilen özel bir mikroorganizma birlikteliğinin faaliyetleriyle ilişkili biyolojik bir süreçtir (Anonim, 2025). Biyogaz, metan (50-60%), karbondioksit (40-50%), nitrojen (%5) gibi gazlardan oluşan renksiz, kokusuz, havadan hafif bir gazdır (Aguilar-Virgen ve ark., 2014; Barros ve ark., 2014; Amini ve ark., 2012; Schneider ve ark., 2012). Her çeşit hayvanın gübresinden ve özellikle içeriğinde yüksek oranda yağ, şeker, nişasta ve karbonhidrat içeren yan ürünlerden tarımsal kökenli biyogaz elde edilebilmektedir. Ancak sığır gübresinin bünyesinde anaerobik fermantasyonu sağlayan mikroorganizmalar olduğu için bu grup organik atıklar biyogaz üretiminde ayrı bir öneme sahiptirler (Alibaş, 1996). En yaygın kullanımı biyogaz olan biyokütle enerjisinin kullanımı ile enerji sağlamanın yanı sıra atık kontrolünün sağlanması yolu ile çevre kirliliğinin de büyük ölçüde önüne geçilmesi sağlanabilmektedir. Biyogaz, yakıt olarak kullanılmasının yanı sıra bir jenaratör yardımı ile elektrik enerjisine dönüştürülerek de kullanılabilen bir enerji kaynağıdır (McCabe ve ark., 2014; Höhn ve ark., 2013; Korres ve ark., 2010).

Bu çalışmada, Edirne ilindeki büyükbaş, küçükbaş ve kanatlı atıklarından elde edilebilecek enerji potansiyeli hesaplanarak belirlenmiştir.

Materyal ve Yöntem

Materyal

Çalışmada, Edirne ilinin biyogaz üretim ve enerji potansiyelinin belirlenmesi için büyükbaş, küçükbaş ve kanatlı hayvan varlığı sayıları Türkiye İstatistik Kurumu ve Edirne Tarım Orman il müdürlüğü 2023 verilerinden derlenmiştir.

Çalışma Alanı

Edirne, Marmara Bölgesinin Trakya bölümünde 40 30 ve 42 00 kuzey enlemleri ile 26 00, 27 00 doğu boylamları arasında bulunmaktadır. Edirne genel karakteri itibariyle geniş

düzlüklerle, basık tepelerin yer almış bulunduğu bir havzada yer almaktadır. Bu Havza, Kuzey-Doğudan Istıranca, batıdan da Rodop dağlarıyla çevrilmiş bulunmaktadır. Havzanın Kuzey-Batı köşesinde Istıranca ve Rodop kitlesi birbirine yaklaşır, bu ikisinin arasında ise Meriç Vadisi yer alır. Konum itibariyle Türkiye'nin tam batısında bulunan Edirne, 6 276 km^2 Yüzey şekilleri bakımından, İlin kuzeyinde Istıranca dağları, orta bölümünde Ergene havzası, güneyinde Koru dağları ve platolar ile Meriç Ovası ve Deltası bulunmaktadır (Şekil 1). Edirne, Marmara Bölgesinde Kırklareli, Tekirdağ, Çanakkale illeri ve Yunanistan, Bulgaristan devletleri ile sınır komşusu bir ildir. Edirne'ye karayolu ile en yakın ulaşılabilen iller Kırklareli ve Tekirdağ'dır (62-141 km.). Komşu iller arasında en uzak mesafede olan il merkezi ise Çanakkale'dir (223 km). Edirne il hudutları dahilinde 763,5 km karayolu ağı vardır. Bunun 275 km.'si devlet yolu, 418 km.'si il yolu ve 70,5 km.'si otoyoldur. Devlet yolları ve il yollarının tamamı asfalt kaplamadır. Yüzölçümüyle ülke topraklarının binde 8'ini kaplamaktadır. İl merkezinin denizden yüksekliği 41 metredir. İlin alanı, doğudan Kırklareli'nin Pehlivanköy, Merkez, Kofçaz; Tekirdağ'ın Malkara ve Hayrabolu ve Çanakkale'nin Gelibolu ilçeleri ile; batıda Yunanistan; kuzeybatıda Bulgaristan; güneyinde ise Ege denizi ile çevrilidir. Edirne, demiryoluyla İstanbul'a ve Kapıkule üzerinden Avrupa'ya bağlanmış durumdadır. Edirne-İstanbul arası 299 km, Edirne-Kapıkule arası 20 km.dir (Anonim 2024). Edirne ili ve ilçe haritasının krokisi Şekil 1'de verilmiştir (Önder, 2019).

Şekil 1. Edirne ili ve ilçeleri haritasının krokisi

Çalışmada, Edirne ilinin biyogaz üretim ve enerji potansiyelinin belirlenmesi için büyükbaş, küçükbaş ve kanatlı hayvan varlığı sayıları Türkiye İstatistik Kurumu ve Edirne Tarım Orman il müdürlüğü 2023 verilerinden derlenmiştir.

Edirne ilindeki büyükbaş, küçükbaş ve kanatlı hayvan varlığı

Edirne ilindeki 2023 yılı toplam büyükbaş hayvan sayısı 142046 adet, küçükbaş hayvan sayısı 364855 adet ve kanatlı hayvan sayısı 280810 adet olduğu hesaplanmıştır. Edirne ili merkez ve ilçelerindeki büyükbaş, küçükbaş ve kanatlı hayvan sayıları Tablo 1'de verilmiştir.

Tablo 1. Edirne ili büyükbaş hayvan sayıları (Anonim, 2023)

İlçeler	Saf Kültür	Kültür Melezi	Yerli	Manda	Toplam
Merkez	15057	2981	177	287	18502
Enez	5458	8030	216	47	13751
Havsa	16308	1484	0	2	17794
İpsala	10730	11184	100	1	22015
Keşan	19820	5543	0	34	25397
Lalapaşa	9542	5030	0	10	14582
Meriç	4465	390	0	0	4855
Süloğlu	3737	2491	0	10	6228
Uzunköprü	14008	4904	0	0	18922
TOPLAM	**99125**	**42037**	**493**	**391**	**142046**

Tablo 1'e göre, en çok büyükbaş hayvan varlığı 25397 adet ile Keşan, 22015 adet ile İpsala ve 18502 adet ile Merkez ilçelerindedir. Toplam saf kültür sayısı 99125 adet, kültür melezi 42037 adet, yerli 493 adet ve en az büyükbaş hayvan manda olup 391 adettir. Edirne ilinin küçükbaş hayvan sayıları Tablo 2'de verilmiştir.

Tablo 2. Edirne ilinin küçükbaş hayvan sayıları (Anonim, 2023)

İlçeler	Koyun (Merinos)	Koyun (Yerli)	Keçi (Kıl keçisi ve diğerleri)	Toplam
Merkez	10112	27254	1487	38068
Enez	27254	3257	14263	44774
Havsa	3391	19266	450	23107
İpsala	4317	33053	3520	40890
Keşan	5214	55089	27338	87641
Lalapaşa	32712	0	1916	34628
Meriç	586	13384	4034	18004
Süloğlu	1912	15628	857	18397
Uzunköprü	4804	50561	3981	59346
TOPLAM	**90302**	**216707**	**57846**	**364855**

Tablo 2'ye göre, en çok küçükbaş hayvan varlığı 87641 adet ile Keşan, 59346 adet ile Uzunköprü ve 44774 adet ile Enez ilçelerindedir. Toplam koyun (merinos) sayısı 90302 adet, yerli koyun sayısı 216707 adet ve toplam kıl keçisi sayısı ise 57846 adettir. Edirne ilinin kanatlı hayvan sayıları Tablo 3'de verilmiştir.

Tablo 3. Edirne ilinin kanatlı hayvan sayıları (Anonim, 2023)

İlçeler	Hindi	Kaz	Ördek ve Beç Tavuğu	Yumurta Tavuğu	Toplam
Merkez	3098	1641	1573	31952	38264
Enez	55	353	265	4280	4953
Havsa	302	1415	1720	29550	32987
İpsala	1210	1070	1515	12590	16395
Keşan	386	710	958	16816	18870
Lalapaşa	375	241	388	9751	10755
Meriç	1384	793	758	16680	19615
Süloğlu	389	296	517	12105	13307
Uzunköprü	1540	1367	2790	38977	44674
TOPLAM	**8739**	**7886**	**10484**	**172701**	**199810**

Tablo 3'e göre, en çok kanatlı hayvan varlığı 44674 adet ile Uzunköprü, 38264 Merkez ve 32987 adet ile Havsa ilçelerindedir. Toplam yumurta tavuğu sayısı 172701 adet, hindi sayısı 8743 adet, kaz sayısı 7886 adet ve ördek-beç tavuğu sayısı 10484 adettir.

Yöntem

Materyal kısmında verilen tablolardan faydalanılarak; Akbulut ve Dikici (2004)'ye göre, "Biyogaz potansiyelini belirlemek için aşağıdaki kabuller ve araştırma sonuçları kullanılmıştır (Deniz, 1987)".

Gübre ile ilgili kabuller: Büyükbaş hayvandan 3.6 ton/yıl gübre, küçükbaş hayvandan 0.7 ton/yıl gübre, kanatlı hayvandan 0.022 ton/yıl gübre ortalama olarak elde edildiği kabul edilir. Gübrelerin yaklaşık 1/3'ünün meralarda kaybolduğu dikkate alınmıştır.

Biyogaz ile ilgili araştırma sonuçları: 1 ton büyükbaş hayvan gübresinden 33 m^3 biyogaz, 1 ton küçükbaş hayvan gübresinden 58 m^3 biyogaz, 1 ton kanatlı hayvan gübresinden 78 m^3 biyogaz elde edildiği araştırma sonucu bulunmuştur.

Biyogazın elektrik enerjisi olarak eşdeğeri

Akbulut ve Dikici (2004)'ye göre, "1 m^3 biyogazın elektrik enerjisi cinsinden değeri; 1 m^3 biyogaz 4.70 kWh enerjidir (Bilir ve ark. 1983)".

Bu kabuller, araştırma sonuçları ve verilere göre Edirne ilindeki toplam hayvan sayısına göre gübre, biyogaz ve enerji potansiyeli hesabı yapılmıştır.

Araştırma Sonuçları ve Tartışma

Büyükbaş, küçükbaş ve kanatlı hayvan varlığından elde edilebilecek hesaplanan gübre miktarları Tablo 4'de verilmiştir.

Tablo 4. Büyükbaş, küçükbaş ve kanatlı hayvan varlığından elde edilebilecek gübre miktarları

Hayvan türü	Toplam hayvan sayısı	Gübre (ton/yıl)	Net gübre*
Büyükbaş	142046	511365,60	340910,40
Küçükbaş	364855	255398,50	170265,67
Kanatlı	199810	4395,82	2930,55

*: gübrelerin yaklaşık 1/3'ünün meralarda kaybolduğu dikkate alınmıştır.

Tablo 4'e göre, bir yılda elde edilebilecek net büyükbaş gübre miktarı 340910,40 ton, küçükbaş gübre miktarı 170265,67 ton ve kanatlı gübre miktarı ise 2930,55 ton'dur. Bu verilere göre Edirne ilinde elde edilebilecek biyogaz ve elektrik enerjisi potansiyeli Tablo 5'de verilmiştir.

Tablo 5. Edirne ilinde elde edilebilecek biyogaz ve elektrik enerjisi potansiyeli

Hayvan türü	Biyogaz (m^3/yıl)	Elektrik (kWh/yıl)	MJ/yıl	GJ/yıl
Büyükbaş	11250043,20	52875203,04	190350730,94	190350,73
Küçükbaş	9875408,67	46414420,73	167091914,64	167091,91
Kanatlı	228582,64	1074338,41	3867618,27	3867,62
Toplam	21354034,51	100363962,18	361310263,85	361310,26

Not: 1 kWh elektrik enerjisinin MJ ve GJ çevrimi için (Anonim, 2015a)'den faydalanılmıştır.

Tablo 5'e göre, büyükbaş hayvan varlığından elde edilebilecek enerji miktarı 190350,73 GJ, küçükbaş hayvan varlığından 167091,91 GJ ve kanatlı hayvan varlığından ise 3867,62 GJ olarak hesaplanmıştır.

Sonuç ve Öneriler

Edirne gerek hayvansal üretim gerekse bitkisel üretim yönünden oldukça verimli olan bir ilimiz olup, özellikle küçükbaş hayvan yetiştiriciliğiyle ön plana çıkmaktadır. İlde küçükbaş hayvan yetiştiriciliği meraya bağımlı ekstansif koşullara bağlı olarak yapılmaktadır. Genellikle büyük sürüler halinde yetiştiricilik yapılmaktadır. Bu nedenle küçükbaş hayvan yetiştiriciliğinden gelen yan ürün miktarları hesaplamalara dahil edilememektedir. Bunun yanı sıra büyükbaş hayvan yetiştiriciliği genel olarak küçük aile işletmeciliği şeklinde yapılmaktadır. Her ne kadar toplam hayvan sayısı göz önünde bulundurularak yapılan hayvansal yan ürün hesaplamalarında teorik olarak çok büyük değerlere ulaşılsa bile toplanabilirlik yönünden bu değerler biyogaz üretimlerinde aynı şekilde kullanılamamaktadır. Fakat potansiyel değer olarak bakıldığında Edirne ilinin biyogaz üretimi ile elde edilecek net elektrik enerjisi potansiyeli yıllık 361310,26 GJ olarak karşımıza çıkmaktadır. Görüldüğü üzere, Edirne ilinin hayvansal atıklarından elde edilen enerji potansiyeli ve bu hayvansal atıkların bir biyogaz tesisi ile enerjiye dönüştürülmesi Edirne ili ve Türkiye ekonomisi açısından önem arz etmektedir.

Kaynaklar

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KARBON VE SU AYAK İZİ GEZEGENİMİZİN GELECEĞİ İÇİN EN SON KEŞİFLER, KÜRESEL ETKİLER VE YENİLİKÇİ ÇÖZÜMLER

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Özet
Bu çalışmada, küresel iklim değişikliği ve su kıtlığı krizlerinin merkezinde yer alan karbon ve su ayak izi kavramlarını derinlemesine incelemektedir. Çalışma, bu iki kritik çevresel göstergenin tanımlarını, ölçüm metodolojilerini, küresel kaynaklarını ve çevresel/sosyo-ekonomik etkilerini kapsamlı bir şekilde ele almaktadır. Özellikle son bilimsel keşifler, teknolojik atılımlar ve politika yenilikleri vurgulanarak, günümüzün en güncel bilgileri sunulmaktadır. Araştırma, atmosferik CO_2 konsantrasyonlarındaki rekor artışlardan dijitalleşmenin gizli karbon ayak izine, yeraltı suyu tükenmesinin uydu tabanlı izlenmesinden mikroplastiklerin su kaynakları üzerindeki etkilerine kadar çeşitli yeni bilgileri ve keşifleri bir araya getirmektedir. Ayrıca, karbon ve su ayak izlerinin kesişim noktası olan Su-Enerji-Gıda Bağlantısı (Nexus) yaklaşımı, "mavi karbon" konsepti ve rejeneratif tarım gibi entegre çözüm önerileri de detaylandırılmıştır. Seminer, sadece sorunları ortaya koymakla kalmayıp, yenilenebilir enerjideki çığır açan gelişmelerden ileri su arıtma teknolojilerine, yapay zeka destekli optimizasyonlardan döngüsel ekonomi modellerine kadar bir dizi inovatif azaltım stratejisi ve gelecek perspektifini sunmaktadır. Amacımız, bireylerden hükümetlere kadar her düzeyde acil eylem için bilimsel temelli, kapsamlı bir çağrı yapmak ve daha sürdürülebilir bir gelecek için umut verici yol haritaları sunmaktır.
Anahtar Kelimeler: Karbon Su ayak izi, küresel etkiler

Not: Bu çalışma Halil Kineyn'in Yüksek Lisans Seminerinden derlenmiştir.

CARBON AND WATER FOOTPRINT LATEST DISCOVERIES, GLOBAL IMPACTS AND INNOVATIVE SOLUTIONS FOR THE FUTURE OF OUR PLANET

Abstract
This study explores in depth the concepts of carbon and water foot printing, which are at the center of the global climate change and water scarcity crises. The study comprehensively covers the definitions, measurement methodologies, global sources and environmental/socio-economic impacts of these two critical environmental indicators. The most up-to-date information is presented today, with particular emphasis on recent scientific discoveries, technological breakthroughs and policy innovations. The research brings together new information and discoveries ranging from record increases in atmospheric CO_2 concentrations to the hidden carbon footprint of digitalization, from satellite-based monitoring of groundwater depletion to the impacts of microplastics on water resources. In addition, integrated solutions such as the Water-Energy-Food Nexus (Nexus) approach, the "blue carbon" concept and regenerative agriculture, which are the intersection of carbon and water footprints, are also detailed. The seminar not only presents the problems, but also presents a range of innovative reduction strategies and future perspectives, from groundbreaking developments in renewable energy to advanced water treatment technologies, from AI-supported optimizations to circular economy models. Our aim is to issue a science-based, comprehensive call for urgent action at all levels, from individuals to governments, and to offer promising roadmaps for a more sustainable future.
Key Words: Carbon Water footprint, global impacts

Giriş

Günümüz dünyası, insan faaliyetlerinin neden olduğu benzeri görülmemiş çevresel zorluklarla karşı karşıyadır. İklim değişikliği, su kıtlığı, biyoçeşitlilik kaybı ve kirlilik, gezegenimizin ekolojik dengesini tehdit etmekte ve insan refahı için ciddi riskler oluşturmaktadır. Bu zorlukların anlaşılması ve yönetilmesi için, insanlığın gezegen üzerindeki etkisini ölçen ve görselleştiren araçlar kritik öneme sahiptir. Bu bağlamda, "karbon ayak izi" ve "su ayak izi" kavramları, bireysel, kurumsal ve ulusal düzeyde çevresel sorumluluğun ve sürdürülebilirlik çabalarının temel göstergeleri haline gelmiştir (Hertwich & Wood, 2018).

Karbon ayak izi, bir bireyin, kurumun, ürünün veya hizmetin doğrudan ve dolaylı olarak neden olduğu toplam sera gazı emisyonlarının bir ölçüsüdür. Esasen, iklim değişikliğinin ana itici gücü olan insan kaynaklı karbon emisyonlarının izini sürer. Su ayak izi ise, benzer şekilde, bir ürünün üretimi, bir hizmetin sunumu veya bir bireyin yaşam tarzı boyunca kullanılan toplam tatlı su miktarını, hem doğrudan hem de dolaylı olarak ölçer. Bu iki ayak izi, doğal kaynakların kullanımının ve çevreye verilen zararın somut bir resmini sunarak, sorunları anlamamıza ve çözüm yolları geliştirmemize yardımcı olur (Hoekstra & Mekonnen, 2012).

Bu seminer araştırması, karbon ve su ayak izi kavramlarını derinlemesine incelemeyi, en güncel bilimsel keşifleri ve teknolojik yenilikleri sunmayı ve bu iki kritik alan arasındaki karmaşık bağlantıları ortaya koymayı amaçlamaktadır. Amacımız, sadece tanımlar ve temel bilgilerle sınırlı kalmayıp, konuya ilişkin en son araştırmaları, IPCC ve Birleşmiş Milletler gibi saygın kuruluşların raporlarını, çığır açan teknolojik gelişmeleri ve başarılı uygulama örneklerini bir araya getirerek, alanındaki en kapsamlı ve ileri düzey araştırmalardan birini sunmaktır.

Araştırma, multidisipliner bir yaklaşımla, çevre bilimleri, ekonomi, mühendislik, politika ve sosyoloji alanlarındaki gelişmeleri entegre etmektedir. Metodolojik olarak, geniş bir literatür taraması yapılmış, akademik makaleler, bilimsel dergiler, uluslararası raporlar ve vaka çalışmaları incelenmiştir. Çalışma, karbon ve su ayak izi kavramlarının sadece birer ölçüm aracı olmanın ötesinde, sürdürülebilir bir gelecek inşa etme yolunda atılacak adımlar için birer pusula görevi gördüğünü vurgulamaktadır.

Bu çalışma, dört ana bölümden oluşmaktadır: İlk bölümde karbon ayak izi, ikinci bölümde su ayak izi ele alınacaktır. Üçüncü bölüm, bu iki ayak izinin kesiştiği, su-enerji-gıda bağlantısı gibi entegre konulara odaklanacaktır. Son bölümde ise gelecek perspektifleri, karşılaşılan zorluklar ve yakalanabilecek fırsatlar değerlendirilecektir. Her bölümde, özellikle "yeni bilgiler ve keşifler" başlığı altında, konuya ilişkin en güncel ve çığır açan gelişmeler sunularak, okuyucunun veya dinleyicinin konuya en üst düzeyde hakim olması hedeflenmektedir. Sonuç bölümü, temel bulguları özetleyerek ve bireysel, kurumsal ve hükümet düzeyinde acil eylem çağrısı yaparak, gezegenimizin geleceği için umut verici bir vizyon sunacaktır.

1. KARBON AYAK İZİ: İKLİM KRİZİNİN PARMAK İZLERİ

1.1. Karbon Ayak İzi: Tanım, Kapsam ve Ölçüm Birimleri

Karbon ayak izi, bir bireyin, etkinliğin, ürünün, organizasyonun veya ülkenin, atmosferdeki sera gazı konsantrasyonlarını artıran doğrudan veya dolaylı emisyonlarının toplam miktarıdır. Genellikle karbondioksit eşdeğeri (CO_2e) olarak ifade edilir, çünkü metan (CH_4), nitröz oksit (N_2O) ve florlu gazlar gibi diğer sera gazlarının iklim değişikliğine katkıları, küresel ısınma potansiyelleri (GWP) dikkate alınarak karbondioksit cinsinden dönüştürülür (IPCC, 2021).

Kapsam açısından üç ana kategoriye ayrılır:

- **Kapsam 1 (Doğrudan Emisyonlar):** Kuruluşun veya bireyin kontrolü altındaki kaynaklardan doğrudan yayılan emisyonlar (örn. şirket araçlarından yakıt yanması, fabrika bacalarından çıkan gazlar) (ISO, 2018).
- **Kapsam 2 (Enerji Dolaylı Emisyonlar):** Kuruluşun veya bireyin satın aldığı elektrik, buhar, ısı veya soğutma üretimi sonucu oluşan emisyonlar (genellikle elektrik santrallerinde oluşur) (GHG Protocol, 2021).
- **Kapsam 3 (Diğer Dolaylı Emisyonlar):** Kuruluşun veya bireyin faaliyetlerinden kaynaklanan, ancak Kapsam 1 veya Kapsam 2 kapsamında olmayan tüm diğer dolaylı emisyonlar (örn. tedarik zinciri, iş seyahatleri, çalışanların işe gidip gelmeleri, atık yönetimi, satılan ürünlerin kullanım ömrü sonu). Kapsam 3, genellikle en büyük payı oluşturur ve ölçülmesi en zor olanıdır (Hertwich & Wood, 2018).
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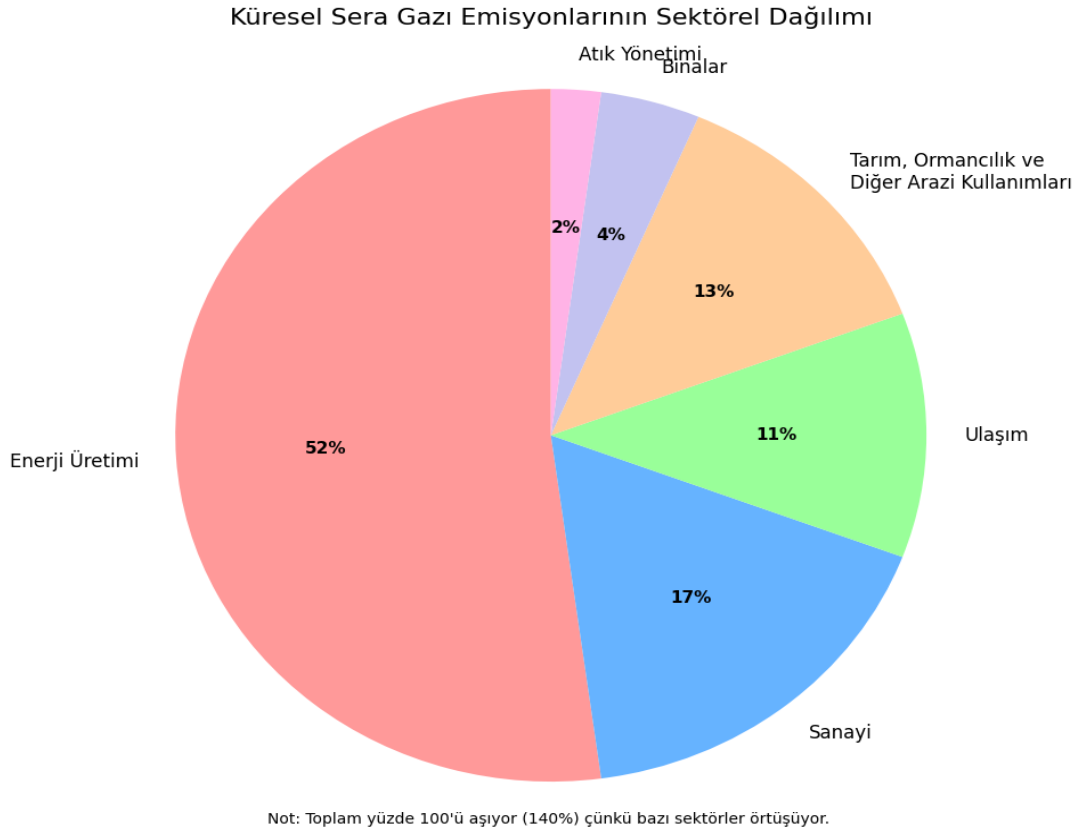
Şekil1. Karbon Ayak izi kapsamları

1.2. **Karbon Ayak İzinin Küresel Kaynakları ve Sektörel Dağılımı**

Küresel sera gazı emisyonlarının ana kaynakları şunlardır:

- **Enerji Üretimi (%73):** Fosil yakıtlara dayalı elektrik ve ısı üretimi, ana emisyon kaynağıdır.
- **Ulaşım (%16):** Karayolu, deniz, hava ve demiryolu taşımacılığı.
- **Sanayi (%24):** Çimento, demir-çelik, kimya gibi ağır sanayi süreçleri ve yakıt kullanımı.
- **Tarım, Ormancılık ve Diğer Arazi Kullanımları (%18):** Hayvancılık (metan), gübre kullanımı (nitröz oksit), ormansızlaşma (karbon yutaklarının kaybı).
- **Binalar (%6):** Konut ve ticari binaların ısıtma, soğutma ve elektrik tüketimi.
- **Atık Yönetimi (%3):** Katı atık depolama alanlarından metan emisyonları (IPCC, 2022).



Şekil 2. Küresel sera gazı emisyonları sektörel dağılımları

1.3. **Ölçüm Metodolojileri: Yaşam Döngüsü Analizi (LCA) ve Diğer Yaklaşımlar** Karbon ayak izi hesaplamasında en yaygın kullanılan yöntem, bir ürünün, hizmetin veya sürecin "beşikten mezara" kadar olan tüm yaşam döngüsü boyunca çevresel etkilerini değerlendiren **Yaşam Döngüsü Analizi (LCA)**'dir. LCA, hammaddenin çıkarılmasından üretim, taşıma, kullanım ve atık aşamasına kadar her adımı kapsar. Diğer metodolojiler arasında kurumsal emisyon envanterleri (GHG Protokolü), ürün kategori kuralları (PCR), karbon denetimleri ve basit karbon hesaplayıcıları bulunur (Hertwich & Wood, 2018). ISO 14064 ve ISO 14067 gibi uluslararası standartlar, hesaplamaların tutarlılığını ve güvenilirliğini sağlamak için rehberlik sunar (ISO, 2018).

1.4. **Yeni Bilgiler ve Keşifler: Karbon Döngüsünde Son Gelişmeler ve Bilinmeyenler**

- **Atmosferik CO2 Konsantrasyonlarındaki Son Rekorlar ve Etkileri (IPCC En Son Raporları):** IPCC'nin Altıncı Değerlendirme Raporu (AR6) ve Sentez Raporu (2023), atmosferdeki CO2 konsantrasyonlarının sanayi öncesi döneme göre %50 artarak 420 ppm'i aştığını ve bunun son 800.000 yılın en yüksek seviyesi olduğunu teyit etmiştir. Rapor, mevcut emisyon eğilimlerinin Paris Anlaşması'nın 1.5°C hedefini imkansız hale getirdiğini, geri dönüşü olmayan eşik noktalarına yaklaşıldığını (örneğin, Grönland ve Batı Antarktika buz tabakalarının erimesi, Amazon'un kuraklaşması) ve küresel ısınmanın beklenenden daha hızlı ilerlediğini vurgulamıştır. Özellikle ani iklim değişikliği olaylarının (flash droughts, atmospheric rivers) sıklığındaki artışlar dikkat çekmektedir (IPCC, 2021).
- **Gizli Karbon Kaynakları: Çözülen Permafrost ve Okyanus Asitlenmesinin Geri Beslemeleri:** Yeni araştırmalar, Sibirya ve Kuzey Amerika'daki donmuş toprakların (permafrost) küresel ısınma nedeniyle çözülmeye başlamasıyla büyük miktarda metan ve karbondioksitin atmosfere salındığını ortaya koymaktadır. Bu, ısınmayı daha da

hızlandıran bir "pozitif geri besleme döngüsü" yaratmaktadır. Aynı zamanda, okyanusların insan kaynaklı CO2'nin büyük bir kısmını emmesi, okyanus asitlenmesine yol açarak deniz ekosistemleri (özellikle mercan resifleri ve kabuklu deniz canlıları) için ciddi tehdit oluşturmakta ve okyanusların karbon yutma kapasitesini azaltmaktadır. Bu, daha az karbon emiliminin daha fazla atmosferik CO2 anlamına geldiği bir başka geri besleme döngüsüdür (IPCC, 2021).

- **Dijitalleşmenin Karbon Ayak İzi: Veri Merkezleri, Kripto Paralar ve Yapay Zekanın Enerji Tüketimi:** Sanıldığının aksine, dijital dünya devasa bir enerji tüketimine sahiptir. Veri merkezleri, küresel elektrik tüketiminin yaklaşık %1-2'sini oluşturmakta ve emisyonları hava taşımacılığı sektörüne yaklaşıyor. Kripto para madenciliği (özellikle Bitcoin), muazzam elektrik kullanımı nedeniyle büyük karbon ayak izine sahiptir; bazı tahminlere göre tek bir Bitcoin işlemi Norveç'teki bir hanenin bir aylık elektrik tüketimine eşdeğer olabilir. Yapay zeka (AI) modellerinin eğitimi ve çalıştırılması için gereken hesaplama gücü de hızla artmakta, bu da AI'nın gelecekteki karbon ayak izi hakkında endişeleri gündeme getirmektedir. Araştırmalar, büyük dil modellerinin (LLM) eğitilmesi için tonlarca CO2 yayılabileceğini göstermektedir (Carbon Direct, 2024).
- **Tedarik Zincirlerindeki Karmaşıklık ve Karbon Kaçağı Sorunları:** Küresel tedarik zincirleri, Kapsam 3 emisyonlarının büyük bir kısmını oluşturur ve şirketlerin karbon ayak izinin %80-90'ına kadar çıkabilir. Ancak bu emisyonların izlenmesi ve raporlanması son derece karmaşıktır. "Karbon kaçağı" (carbon leakage) ise, emisyon düzenlemeleri sıkı olan ülkelerdeki şirketlerin, üretimlerini daha gevşek düzenlemelere sahip ülkelere taşımasıyla ortaya çıkan bir sorundur. Bu, küresel emisyonlarda net bir azalma sağlamazken, ekonomik ve sosyal eşitsizlikleri artırabilir. Blokzincir teknolojisi ve yapay zeka destekli platformlar, tedarik zinciri şeffaflığını artırarak bu sorunlara çözüm arayışında yeni umutlar sunmaktadır (IBM Research, 2024).

1.5. **Karbon Ayak İzinin Çevresel ve Sosyo-Ekonomik Etkileri**

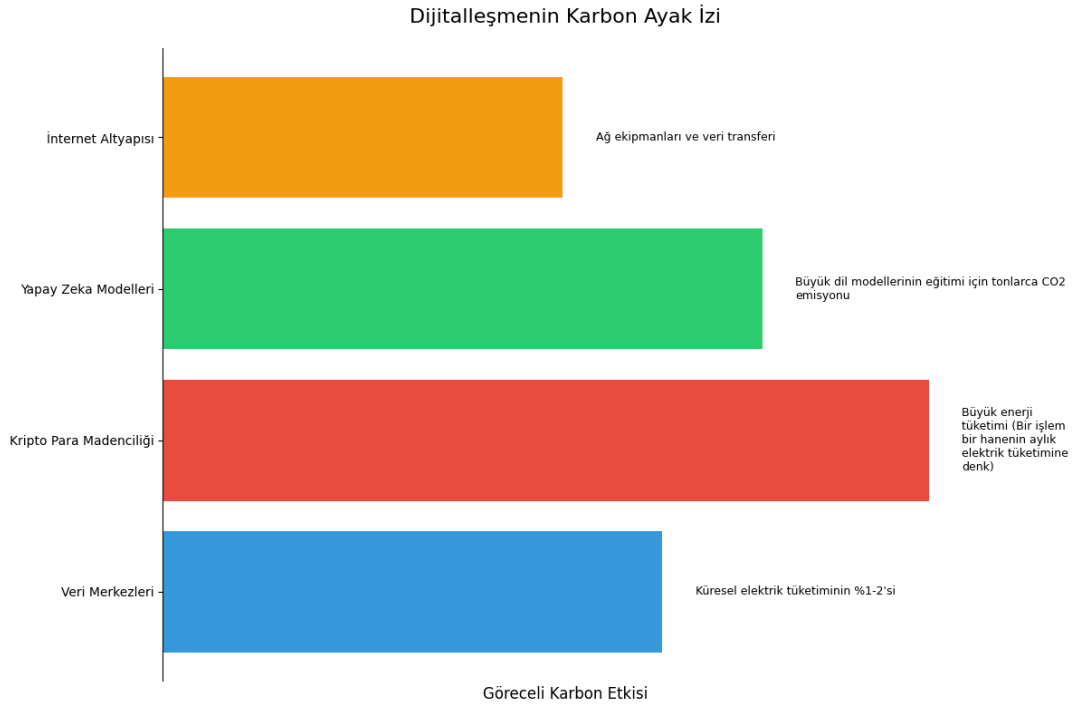
- **İklim Değişikliği, Aşırı Hava Olayları, Biyoçeşitlilik Kaybı:** Artan karbon emisyonları, küresel ısınmaya, buzulların ve buz tabakalarının erimesine, deniz seviyesinin yükselmesine, okyanus akıntılarının değişmesine ve aşırı hava olaylarının (şiddetli fırtınalar, sel, kuraklık, sıcak hava dalgaları, orman yangınları) sıklığının ve yoğunluğunun artmasına neden olmaktadır. Bu durum, ekosistemlerin bozulmasına, türlerin yok olmasına ve biyoçeşitlilik kaybına yol açmaktadır (IPCC, 2022).
- **Sağlık Etkileri, Göç Hareketleri, Ekonomik Maliyetler:** İklim değişikliği, hava kalitesinin bozulması, su ve gıda güvenliğinin tehlikeye girmesi, vektör kaynaklı hastalıkların yayılması ve ısı stresi gibi doğrudan sağlık sorunlarına neden olmaktadır. Kaynak kıtlığı ve doğal afetler, iklim göçmenlerinin sayısını artırarak sosyal istikrarsızlığa yol açmaktadır. Aşırı hava olaylarının neden olduğu altyapı hasarları, tarım ürünlerindeki kayıplar ve üretim kesintileri, küresel ekonomiye trilyonlarca dolarlık maliyet bindirmektedir (Gleick, 2014).

1.6. **Azaltım Stratejileri ve İnovatif Çözümler: Karbonsuz Bir Geleceğe Doğru**

- **Yenilenebilir Enerji Teknolojilerindeki Son Gelişmeler:**
  - **Gelişmiş Güneş Panelleri:** Perovskit, organik ve kuantum noktası teknolojileriyle daha verimli, esnek ve düşük maliyetli güneş panelleri geliştirilmektedir.
  - **Yeşil Hidrojen:** Su elektrolizi ile yenilenebilir enerji kullanılarak üretilen hidrojen, ağır sanayi, ulaşım ve depolama için geleceğin yakıtı olarak görülmektedir. Gelişmiş elektrolizör tasarımları ve yeni katalizörler, üretim maliyetlerini düşürmeyi hedeflemektedir.

- **Gelişmiş Rüzgar Türbinleri:** Daha yüksek kapasite faktörlü, daha büyük ve daha verimli (örn. yüzer açık deniz rüzgar türbinleri) tasarımlar.
- **Füzyon Enerjisi Araştırmaları:** ITER (Uluslararası Termonükleer Deneysel Reaktör) projesi gibi büyük ölçekli uluslararası işbirlikleri, "yıldızların enerjisi" olarak adlandırılan füzyon enerjisini temiz ve sınırsız bir enerji kaynağı olarak ticarileştirmek için önemli ilerlemeler kaydetmektedir (IPCC, 2022).

- **Karbon Yakalama, Kullanım ve Depolama (CCUS) Teknolojilerindeki Son Yenilikler:** Doğrudan Hava Yakalama (DAC) tesisleri, atmosferden karbondioksiti doğrudan yakalama kapasitesini artırmaktadır. Yakalanan CO2'nin jeolojik oluşumlarda depolanması veya endüstriyel süreçlerde (örn. sentetik yakıt üretimi, beton kürleme) kullanılması için yeni pilot projeler ve ticarileşme çalışmaları hızlanmaktadır. Örneğin, İsviçreli Climeworks veya Kanadalı Carbon Engineering gibi şirketler bu alanda öncülük etmektedir (Climeworks, 2022).



Şekil 3. Dijitalleşmenin karbon ayak izi

- **Döngüsel Ekonomi Modelleri ve Endüstriyel Simbiyoz:** Hammadde kullanımını ve atık oluşumunu minimuma indiren, ürünlerin ömrünü uzatan ve atıkları kaynak olarak gören döngüsel ekonomi prensipleri yaygınlaşmaktadır. Endüstriyel simbiyozda ise, bir sanayi tesisinin atığı, başka bir tesisin hammaddesi veya enerji kaynağı olarak kullanılır (örn. Kalundborg, Danimarka). Bu, hem karbon emisyonlarını hem de kaynak tüketimini azaltır (Ellen MacArthur Foundation, 2023).
- **Sürdürülebilir Ulaşım ve Akıllı Şehirler:** Elektrikli araçlar, hidrojen yakıt hücreli araçlar, gelişmiş toplu taşıma sistemleri ve akıllı trafik yönetimi sistemleri karbon emisyonlarını azaltmaktadır. Akıllı şehirler, entegre ulaşım ağları, enerji verimli binalar ve akıllı şebekeler aracılığıyla karbon ayak izini düşürmeyi hedeflemektedir.
- **Yapay Zeka ve Büyük Veri ile Optimizasyon:** AI, enerji şebekelerinin optimizasyonu, binaların enerji verimliliğinin artırılması, tedarik zincirlerinin iyileştirilmesi ve endüstriyel süreçlerin daha az enerji tüketimiyle çalışması için devasa potansiyel sunmaktadır. Büyük veri analizi, emisyon kaynaklarını daha doğru belirlemeye ve azaltım stratejilerini kişiselleştirmeye yardımcı olmaktadır (Carbon Direct, 2024).

1.7. **Uluslararası Anlaşmalar, Politikalar ve Kurumsal Sorumluluk**

- **Paris Anlaşması:** Küresel ısınmayı sanayi öncesi seviyelerin 2°C altında tutma ve 1.5°C ile sınırlama çabalarını sürdürme hedefini ortaya koyan, tüm ülkeleri kapsayan küresel bir anlaşmadır. Ulusal Olarak Belirlenmiş Katkılar (NDC'ler) ile ülkelerin kendi hedeflerini belirlemesini sağlar (UNFCCC, 2015).
- **AB Yeşil Mutabakatı:** Avrupa Birliği'ni 2050 yılına kadar dünyanın ilk iklim nötr kıtası yapma amacı taşıyan kapsamlı bir yol haritasıdır. Karbon piyasası, sınırda karbon düzenleme mekanizması (CBAM) gibi araçlar içerir (European Commission, 2023).
- **Karbon Fiyatlandırma Mekanizmaları:** Emisyon ticaret sistemleri (ETS) ve karbon vergileri, şirketlerin emisyonlarını azaltmaları için ekonomik teşvikler sunar. Yeni geliştirilen gönüllü karbon piyasaları ve offset mekanizmaları da şirketlerin "net sıfır" hedeflerine ulaşmalarına yardımcı olmaktadır (GHG Protocol, 2021).
- **Kurumsal Sorumluluk ve ESG (Çevresel, Sosyal, Yönetişim) Kriterleri:** Şirketler, sadece finansal performanslarına göre değil, çevresel ve sosyal etkilerine göre de değerlendirilmektedir. ESG yatırımcıları, sürdürülebilirlik taahhütleri olan şirketlere yönelerek piyasayı dönüştürmektedir. Bilim Temelli Hedefler Girişimi (SBTi) gibi platformlar, şirketlerin Paris Anlaşması ile uyumlu emisyon azaltım hedefleri belirlemesine yardımcı olmaktadır (Science Based Targets initiative, 2023).

1.8. **Vaka Çalışmaları: Başarılı Karbon Azaltım Örnekleri**

- **Danimarka:** Özellikle rüzgar enerjisi alanında lider. Elektrik ihtiyacının büyük bir kısmını rüzgardan karşılamakta ve yenilenebilir enerjiye geçiş konusunda iddialı hedefler belirlemektedir.
- **Microsoft:** 2030 yılına kadar "karbon negatif" olma (geçmişteki tüm emisyonlarını atmosferden temizleme) ve 2050 yılına kadar 1975'ten bu yana yaydığı tüm karbonu temizleme taahhüdü ile öne çıkmaktadır. Büyük ölçekli DAC projelerine yatırım yapmaktadır.
- **Stockholm, İsveç:** 2040 yılına kadar fosil yakıtsız olma hedefiyle, akıllı şehir uygulamaları, enerji verimliliği ve sürdürülebilir toplu taşıma sistemleri ile örnek teşkil etmektedir (European Commission, 2023).

Tablo.1. Kurumsal Sorumluluk ve ESG

Vaka Çalışması	**Tür**	**Başarı Öğeleri**	**Sonuçlar**
Danimarka	Ülke	Rüzgar enerjisine yönelik büyük yatırımlar ve iddialı yenilenebilir enerji hedefleri	Elektrik ihtiyacının büyük bir kısmı rüzgardan karşılanarak karbon emisyonlarında önemli azalma
Microsoft	Şirket	2030 yılına kadar "karbon negatif" olma taahhüdü. Doğrudan Hava Yakalama (DAC) projelerine yatırım	Geçmişteki tüm emisyonlarını atmosferden temizleme hedefi ve kurumsal sorumluluk örnekleri
Stockholm, İsveç	Şehir	2040 yılına kadar fosil yakıtsız olma hedefi, akıllı şehir uygulamaları	Sürdürülebilir toplu taşıma ve enerji verimliliği ile şehir ölçeğinde emisyon azaltımı
İsrail	Ülke	Gelişmiş desalinasyon, atık su geri dönüşümü ve akıllı tarım teknolojileri	Su kıtlığına rağmen yüksek su güvenliği. Kullanılan suyun %80'inden fazlası geri dönüştürülerek tarımda kullanım
Singapur	Ülke	"Dört Ulusal Musluk" stratejisi (yerel su toplama, ithal su, NEWater ve desalinasyon)	Kısıtlı su kaynaklarına rağmen tam su güvenliği ve NEWater teknolojisiyle atık suyun içme suyuna dönüştürülmesi
Levi Strauss & Co.	Şirket	Water<Less™ teknolojisinin geliştirilmesi	Kot pantolon üretimindeki su kullanımının önemli ölçüde azaltılması

2. SU AYAK İZİ: YAŞAM KAYNAĞIMIZIN GÖRÜNMEYEN TÜKETİMİ

2.1. Su Ayak İzi: Tanım, Bileşenleri ve Ölçüm Metodolojileri

Su ayak izi, bir ürünün üretimi, bir hizmetin sunumu veya bir bireyin tüketim alışkanlıkları boyunca kullanılan toplam tatlı su hacminin bir ölçüsüdür (Hoekstra & Mekonnen, 2012). Genellikle metreküp (m^3) veya litre cinsinden ifade edilir ve üç ana bileşenden oluşur:

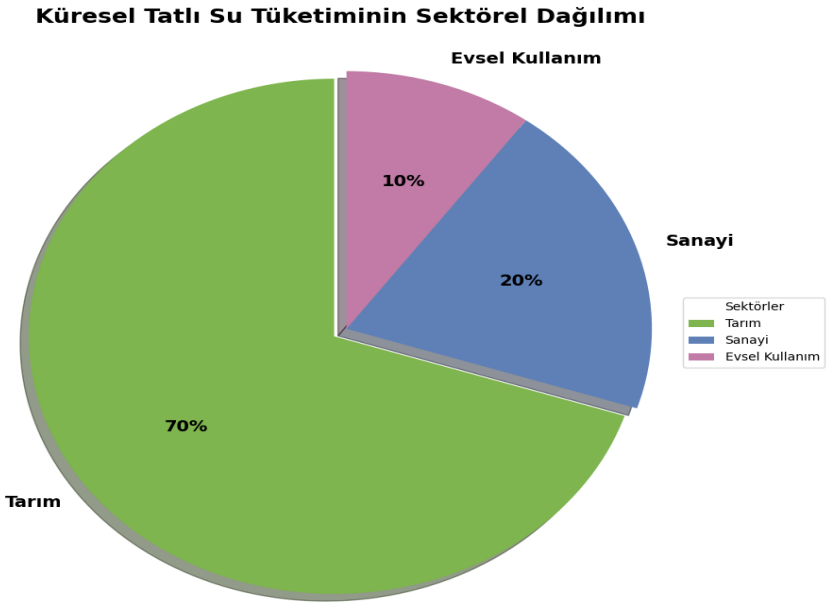
- **Mavi Su Ayak İzi:** Yüzey veya yeraltı sularından alınan ve geri dönmeyen (buharlaşan veya ürün içine katılan) tatlı su miktarıdır. Tarım, sanayi ve evsel kullanımda yaygındır (Water Footprint Network, 2024).
- **Yeşil Su Ayak İzi:** Toprakta depolanan ve bitkiler tarafından kullanılan yağmur suyu miktarıdır. Özellikle tarım ürünlerinin (tahıllar, pamuk) üretiminde önemlidir.
- **Gri Su Ayak İzi:** Kirlilik yükünü (birim kirletici madde) absorbe etmek için gerekli olan tatlı su miktarıdır. Sanayi ve evsel atık suların arıtılması ve seyreltilmesi için gereken su miktarını ifade eder (Hoekstra & Mekonnen, 2012).

Şekil 4. Su ayak izi bileşenleri

Su ayak izi hesaplamaları için Water Footprint Network (WFN) tarafından geliştirilen küresel standartlar ve kılavuzlar kullanılmaktadır. Yaşam Döngüsü Analizi (LCA) yaklaşımı, su ayak izi değerlendirmelerinde de yaygın olarak uygulanmaktadır (Hoekstra & Mekonnen, 2012).

2.2. Küresel Su Kaynakları ve Su Kıtlığı Sorunu

Dünya yüzeyinin %71'i suyla kaplı olmasına rağmen, tatlı su kaynakları oldukça sınırlıdır (küresel suyun yaklaşık %2.5'i). Bunun da büyük bir kısmı buzullarda ve yeraltı suyu olarak kilitlidir; erişilebilir tatlı su miktarı oldukça azdır. Hızla artan nüfus, kirlilik, tarım ve sanayinin artan su talebi, birçok bölgede ciddi su kıtlığına yol açmaktadır. Dünya nüfusunun dörtte birinden fazlasının (yaklaşık 2 milyar kişi) halihazırda su kıtlığı çeken bölgelerde yaşadığı tahmin edilmektedir (Mekonnen & Hoekstra, 2016).

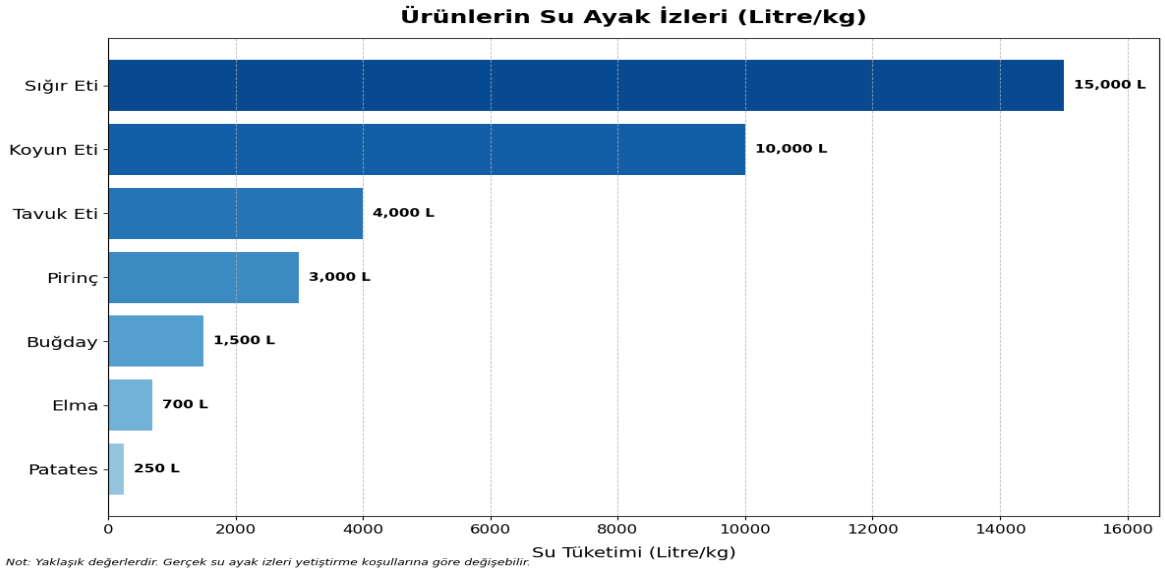


Şekil 5.Küresel tatlı su tüketiminin sektörel dağılımı

2.3. Su Ayak İzinin Sektörel Dağılımı ve Sanal Su Ticareti

Küresel tatlı su tüketiminin yaklaşık %70'i tarım sektörü tarafından (özellikle et üretimi, pirinç ve pamuk gibi su yoğun ürünler için), %20'si sanayi tarafından ve %10'u evsel kullanım tarafından gerçekleştirilmektedir (Water Footprint Network, 2024).

- **Sanal Su Ticareti:** Bir ürünün üretildiği yerde kullanılan su miktarıdır ve ürünün uluslararası ticaretiyle birlikte bir ülkeden diğerine "taşınır". Örneğin, kuru bölgelerdeki ülkeler, su yoğun ürünleri (örn. tahıl, et) ithal ederek kendi su kaynakları üzerindeki baskıyı azaltabilirler. Ancak bu durum, ihracatçı ülkelerdeki su kaynakları üzerinde büyük bir baskı yaratabilir ve su kıtlığını derinleştirebilir. Bu, jeopolitik gerilimlere ve su diplomasisi ihtiyacına yol açabilir. Türkiye gibi tarım ihracatçısı ülkeler için sanal su ihracatının potansiyel etkileri önemlidir (Mekonnen & Hoekstra, 2011).
-



Şekil 6. Bazı Ürünlerin su ayak izleri

2.4. Yeni Bilgiler ve Keşifler: Su Döngüsündeki Değişimler ve Gelişmekte Olan Tehditler

- **Yeraltı Suyu Tükenmesinin Gizli Tehlikeleri ve Uydu Tabanlı İzleme Teknolojileri (GRACE Misyonu vb.):** Dünya genelinde yeraltı suyu rezervleri alarm verici bir hızla tükenmektedir. Özellikle Hindistan, Çin, ABD (California) ve Ortadoğu gibi yoğun tarım yapılan veya kurak bölgelerdeki akiferler aşırı pompaj nedeniyle kritik seviyelere inmiştir. NASA'nın Gravity Recovery and Climate Experiment (GRACE) ve GRACE Follow-On uyduları, yerçekimi alanındaki küçük değişiklikleri ölçerek küresel yeraltı suyu seviyelerindeki değişimleri izlemektedir. Bu veriler, birçok bölgenin net yeraltı suyu kaybı yaşadığını ve bunun telafi edilemeyecek boyutlara ulaştığını ortaya koymuştur. Bu tükenme, toprak çökmesi, deniz suyu girişi (tuzlanma) ve ekosistem bozulmaları gibi ciddi sorunlara yol açmaktadır (Vörösmarty et al., 2010).
- **Mikroplastiklerin Su Kaynakları ve Su Ayak İzi Üzerindeki Etkileri:** Son araştırmalar, mikroplastiklerin (5 mm'den küçük plastik parçacıkları) içme suyu kaynaklarından yeraltı sularına, nehirlerden okyanuslara kadar her yerde bulunduğunu göstermektedir. Bu parçacıklar, su arıtma tesislerinde tam olarak giderilememekte ve besin zincirine girerek insan sağlığı için potansiyel riskler taşımaktadır. Mikroplastik kirliliği, su kaynaklarının kullanılabilirliğini azaltarak ve su arıtma süreçlerinin karmaşıklığını artırarak su ayak izini dolaylı olarak etkilemektedir. Ayrıca, sentetik giysilerin yıkanması, kozmetik ürünleri ve sanayi atıkları gibi yeni mikroplastik kaynaklarının keşfi, su ayak izi hesaplamalarına entegre edilmesi gereken yeni bir boyut katmaktadır (Hoekstra & Mekonnen, 2012).
- **İklim Değişikliğinin Su Döngüsü Üzerindeki Beklenmedik Etkileri (Atmosferik Nehirler, Ani Kuraklıklar):** İklim değişikliği, su döngüsünü tahmin edilenden daha karmaşık ve şiddetli şekillerde değiştirmektedir. "Atmosferik nehirler" (atmospheric rivers), binlerce kilometre uzunluğunda, yoğun nem taşıyan hava akımlarıdır ve bazı bölgelerde yıkıcı sellere neden olurken, başka bölgelerde ani kuraklıkların tetikleyicisi olabilmektedir. Değişen yağış rejimleri, bazı bölgelerde şiddetli kuraklıkları daha sık ve yoğun hale getirirken, diğer bölgelerde aşırı yağış ve sellere yol açmaktadır. Bu öngörülemeyen değişiklikler, su yönetimi stratejilerini ve su ayak izi azaltma çabalarını daha da zorlaştırmaktadır (Water Footprint Network, 2024).

- **"Su-Pozitif" (Water-Positive) Yaklaşımlar ve Şirketlerin Yeni Taahhütleri:** Bazı şirketler, sadece su ayak izlerini azaltmakla kalmayıp, kullandıklarından daha fazla suyu geri kazandırma veya su havzalarını iyileştirme ("su-pozitif" olma) hedefleri belirlemektedir. Coca-Cola, Nestlé ve AB InBev gibi şirketler, lokal su projelerine yatırım yaparak, su havzalarını restore ederek veya su verimliliğini artırarak bu hedeflere ulaşmaya çalışmaktadır. Bu yaklaşım, kurumsal su yönetiminde yeni bir paradigma değişimi temsil etmektedir (Science Based Targets initiative, 2023).

2.5. Su Ayak İzinin Çevresel ve Sosyo-Ekonomik Sonuçları

- **Ekosistem Bozulması, Çölleşme, Biyoçeşitlilik Kaybı:** Su kaynaklarının aşırı kullanımı ve kirliliği, nehirlerin kurumasına, sulak alanların yok olmasına, göllerin küçülmesine ve sucul ekosistemlerin bozulmasına yol açmaktadır. Bu durum, çölleşmeyi hızlandırmakta ve sucul ve karasal biyoçeşitlilik üzerinde yıkıcı etkiler yaratmaktadır (IPCC, 2022).
- **Su Kaynaklı Hastalıklar, Gıda Güvenliği Riskleri, Su Savaşları Potansiyeli:** Temiz suya erişimdeki yetersizlik, kolera, tifo gibi su kaynaklı hastalıkların yayılmasına neden olmaktadır. Tarım için su kıtlığı, gıda üretimini doğrudan etkileyerek gıda güvenliği

riskleri yaratmaktadır. Sınır aşan su kaynaklarının paylaşılamaması, ülkeler arasında "su savaşları" potansiyelini artırarak bölgesel istikrarsızlığa yol açabilir (Gleick, 2014).

2.6. Azaltım Stratejileri ve İnovatif Çözümler: Su Kaynaklarını Koruma ve Yönetme

- **İleri Su Arıtma ve Geri Kazanım Teknolojileri:**

Membran Teknolojileri: Ters Ozmoz (RO), Ultrafiltrasyon (UF), Nanofiltrasyon (NF) ve İleri Oksidasyon Prosesleri (AOP'ler) gibi membran bazlı teknolojiler, atık suları ve hatta tuzlu suları yüksek kalitede içme suyuna dönüştürebilmektedir. Son yıllarda geliştirilen İleri İleri Ozmoz (FO) ve Membran Biyoreaktör (MBR) sistemleri, enerji verimliliği ve kirlilik gideriminde önemli adımlar atmıştır.

Ozonlama ve UV Dezenfeksiyonu: Kimyasal kullanımını azaltarak atık suların dezenfeksiyonu için etkili ve çevre dostu yöntemlerdir (PUB Singapore, 2024).

- **Akıllı Sulama Sistemleri ve Hassas Tarım Uygulamaları:** Sensörler, dronlar, uydu görüntüleri ve yapay zeka kullanarak bitkilerin su ihtiyacını gerçek zamanlı olarak belirleyen sistemler, sulama suyu israfını %50'ye varan oranlarda azaltabilmektedir. Damla sulama, yağmurlama sistemleri ve hidroponik/aeroponik gibi topraksız tarım yöntemleri de su verimliliğini artırmaktadır (Climate Adaptation Platform, 2024).
- **Su Verimli Endüstriyel Prosesler ve Kapalı Döngü Sistemler:** Sanayide, suyu tekrar kullanma, geri dönüştürme ve daha az su tüketen teknolojilere geçiş (örn. hava soğutmalı sistemler yerine su soğutmalı sistemler, üretimde suyun tekrar tekrar kullanıldığı kapalı döngü sistemler) su ayak izini önemli ölçüde azaltmaktadır (Ellen MacArthur Foundation, 2023).
- **Tuzdan Arındırma (Desalinasyon) Teknolojilerindeki Son Gelişmeler:** Enerji yoğunluğu yüksek olan desalinasyon, özellikle kurak bölgelerde içme suyu temini için kritik hale gelmiştir. Yeni nesil membranlar, güneş enerjisiyle çalışan desalinasyon tesisleri ve atık ısıdan faydalanan hibrit sistemler, bu teknolojiyi daha sürdürülebilir hale getirmektedir. Grafen bazlı membranlar ve Elektrodiyaliz gibi yeni teknolojiler, enerji maliyetlerini düşürmeyi hedeflemektedir (Northwestern University, 2023).
- **Yağmur Suyu Hasadı ve Gri Suyun Yeniden Kullanımı:** Çatılardan veya diğer yüzeylerden toplanan yağmur suyunu depolama ve evsel kullanımlar (tuvalet rezervuarları, bahçe sulama) için değerlendirme yaygınlaşmaktadır. Gri su (banyo, lavabo ve çamaşır makinesinden gelen atık su) da basit arıtma işlemlerinden sonra sulama veya tuvaletler için tekrar kullanılabilmektedir (PUB Singapore, 2024).

2.7. Su Yönetimi Politikaları, Su Diplomasisi ve Kurumsal Su Stratejileri

- **Entegre Su Kaynakları Yönetimi (IYKSM):** Su kaynaklarının sürdürülebilir yönetimi için havza bazlı, katılımcı ve çok sektörlü bir yaklaşım benimsenmelidir (Hoff, 2011).
- **Su Diplomasisi:** Sınır aşan su kaynaklarının adil ve sürdürülebilir bir şekilde paylaşılması için uluslararası işbirliği ve anlaşmalar kritik öneme sahiptir.
- **Kurumsal Su Stratejileri:** Şirketler, su risklerini değerlendirmeli, su ayak izlerini azaltma hedefleri belirlemeli ve su kaynaklarının korunmasına yönelik yerel projelere yatırım yapmalıdır (Science Based Targets initiative, 2023).

2.8. Vaka Çalışmaları: Başarılı Su Yönetimi ve Ayak İzi Azaltım Örnekleri

- **İsrail:** Yıllardır su kıtlığıyla boğuşan İsrail, gelişmiş desalinasyon, atık su geri dönüşümü ve akıllı tarım teknolojileri sayesinde su güvenliğini büyük ölçüde sağlamıştır. Kullanılan suyun %80'inden fazlasını geri dönüştürerek tarımda kullanmaktadır (OECD, 2022).
- **Singapur:** Su kaynakları sınırlı olan bu şehir devleti, dört ana kaynaktan oluşan "Dört Ulusal Musluk" stratejisiyle (yerel su toplama, ithal su, NEWater - geri dönüştürülmüş atık su, desalinasyon) su güvenliğini garanti altına almıştır. Özellikle NEWater

teknolojisi, ileri membran filtreleme ve UV dezenfeksiyonu kullanarak atık suyu yüksek kalitede içme suyuna dönüştürmesiyle dünya çapında bir modeldir (Global Water Forum, 2018).

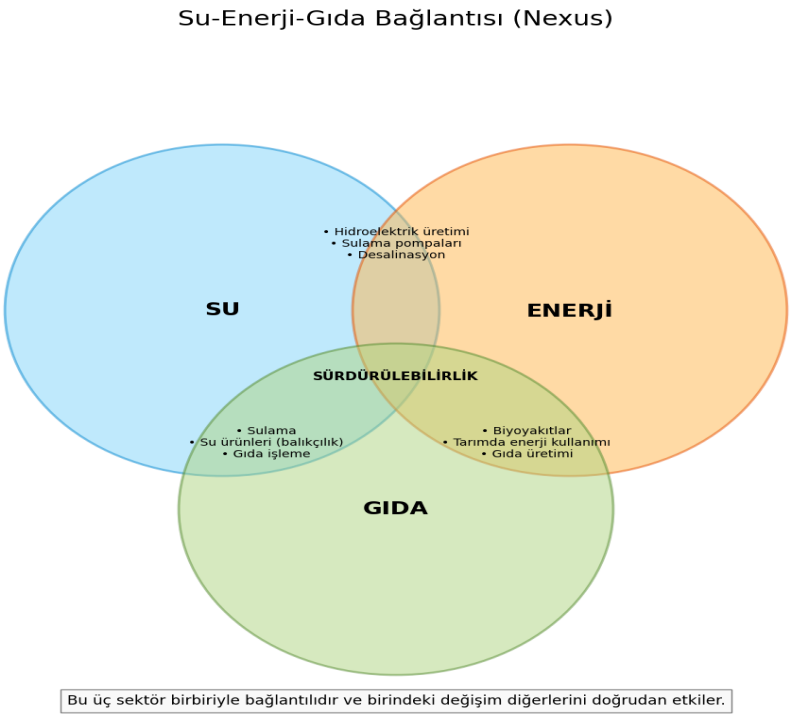
- **Levi Strauss & Co.:** Kot pantolon üretimindeki su yoğunluğunu azaltmak için "Water<Less™" teknolojisini geliştirerek üretim süreçlerindeki su kullanımını önemli ölçüde düşürmüştür (Levi Strauss & Co., 2019). Bu teknoloji, geleneksel yıkama işlemlerinden farklı olarak daha az su kullanarak aynı görünümü elde etmeyi sağlamaktadır (Levi Strauss & Co., 2022).

3. KARBON VE SU AYAK İZLERİNİN KESİŞİMİ: ENTEGRE BİR BAKIŞ AÇISI

3.1. Su-Enerji-Gıda Bağlantısı (Nexus): Birbirine Bağımlılık ve Sinerjiler

Karbon ve su ayak izlerinin birbirini nasıl etkilediğini anlamanın anahtarı, "Su-Enerji-Gıda Bağlantısı" (Water-Energy-Food Nexus) kavramıdır. Bu üç sektör birbirinden ayrı düşünülemez ve birindeki değişim diğerlerini doğrudan etkiler (Dergipark, 2021):

- **Enerji Üretimi İçin Su Kullanımı:** Elektrik üretimi (özellikle termik santrallerde soğutma), hidroelektrik enerji ve biyoyakıt üretimi büyük miktarlarda suya ihtiyaç duyar.
- **Su Temini ve Arıtımı İçin Enerji Tüketimi:** Suyun pompalanması, arıtılması, dağıtılması ve atık suların toplanıp arıtılması önemli miktarda enerji gerektirir. Desalinasyon gibi ileri su temini yöntemleri özellikle enerji yoğundur.
- **Gıda Üretiminin Hem Su Hem de Enerji Talebi:** Tarım, hem su tüketiminin (sulama) hem de enerji tüketiminin (traktörler, pompalar, gübre üretimi) ana sürücüsüdür (Hacettepe Üniversitesi, 2024). Gıda işleme, depolama ve taşıma da önemli enerji ve su ayak izlerine sahiptir (Hoekstra & Mekonnen, 2012).



Şekil 7. Su enerji gıda bağlantısı

Bu bağlantı, tek bir sektördeki bir çözümün, diğerlerinde istenmeyen olumsuz sonuçlar doğurabileceğini gösterir (örn. su kıtlığı nedeniyle daha fazla desalinasyon = daha fazla enerji tüketimi = daha fazla karbon emisyonu). Bu nedenle, entegre, bütüncül çözümlere ihtiyaç vardır.

3.2. İklim Değişikliğinin Su Ayak İzine Etkileri: Artan Buharlaşma, Değişen Yağış Rejimleri, Buzulların Erimesi

İklim değişikliği, karbon ayak izinin bir sonucudur ve su döngüsü üzerindeki etkileriyle su ayak izini doğrudan etkiler:

- **Artan Buharlaşma:** Yüksek sıcaklıklar, göllerden, nehirlerden ve topraktan buharlaşmayı artırarak su kaynaklarını azaltır.
- **Değişen Yağış Rejimleri:** Bazı bölgelerde yağışların azalması (kuraklık), diğerlerinde ise aşırı yağışlar (seller) su kaynaklarının yönetilebilirliğini zorlaştırır.
- **Buzulların ve Kar Örtüsünün Erimesi:** Buzullar ve kar örtüsü, birçok bölgede tatlı suyun doğal deposu görevi görür. Erimeleri başlangıçta su miktarını artırsa da uzun vadede su kaynaklarının tükenmesine ve mevsimsel su kıtlığına yol açar (NASA GRACE, 2022).
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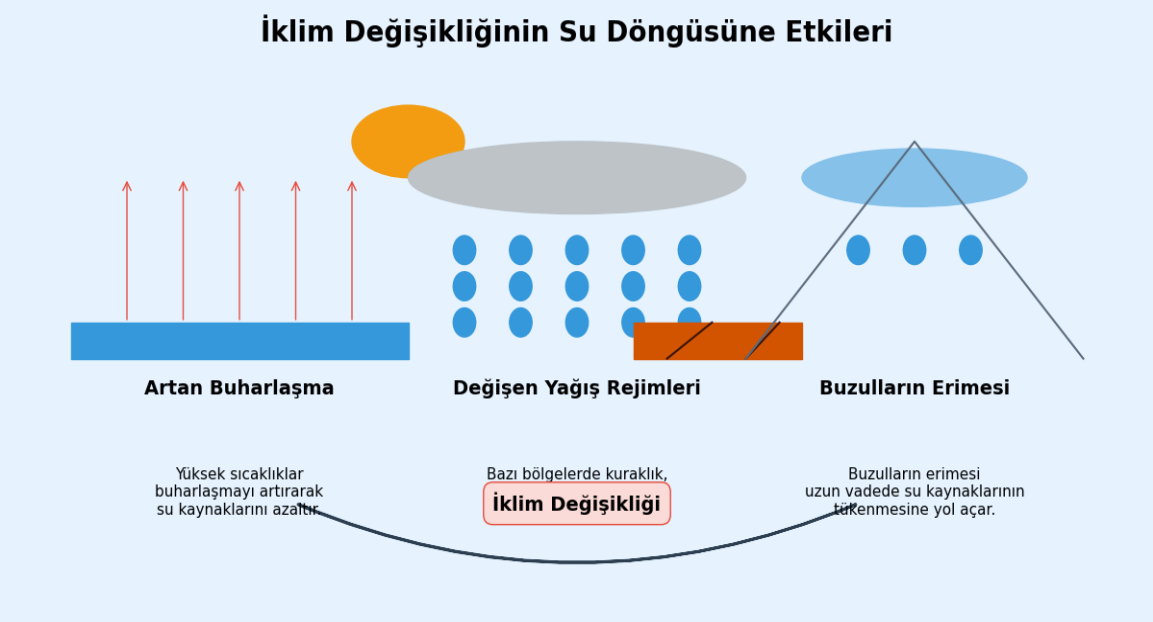


Şekil 8. İklim değişikliğinin Su döngüsüne etkileri

3.3. Yeni Bilgiler ve Keşifler (Entegre Alanlarda):

- **"Mavi Karbon": Kıyısal Ekosistemlerin Hem Karbon Yutakları Hem de Su Kalitesi Regülatörleri Olarak Önemi ve Korunmasındaki Son Gelişmeler:** Mangrovlar, tuzlu bataklıklar ve deniz çayırları gibi kıyısal ve denizel ekosistemler, atmosferden karbondioksiti ("mavi karbon") çok daha hızlı ve daha uzun süreler boyunca sekestre etme (tutma) kapasitesine sahiptir. Ayrıca, bu ekosistemler su kalitesini filtreleyerek, kıyı erozyonunu önleyerek ve deniz canlıları için yaşam alanı sağlayarak su yönetimi ve biyoçeşitlilik için de kritik öneme sahiptir. Son araştırmalar, bu ekosistemlerin restorasyonunun hem iklim değişikliğiyle mücadelede hem de su kıtlığı ve kirliliği sorunlarının çözümünde çifte fayda sağladığını göstermektedir. UNESCO ve IUCN gibi kuruluşlar, "Mavi Karbon Girişimleri" ile bu ekosistemlerin korunması ve restore edilmesi için küresel çabalara öncülük etmektedir (Sustainable Future, 2023).

- **Sürdürülebilir Tarım Pratiklerinin (örneğin, Rejeneratif Tarım, Agroekoloji) Hem Karbon Sekestrasyonunu Artırması Hem de Su Kullanım Verimliliğini İyileştirmesi Üzerine En Son Araştırmalar**
- Rejeneratif tarım ve agroekoloji gibi uygulamalar, toprağın sağlığını iyileştirmeye odaklanır. Toprağa karbon bağlayarak (karbon sekestrasyonu) hem atmosferdeki CO2 miktarını azaltır hem de toprağın su tutma kapasitesini artırır. Bu, daha az sulama suyu gerektirdiği için su kullanım verimliliğini artırır. Örnek uygulamalar arasında minimum toprak işleme, örtü bitkileri, ürün rotasyonu ve kompost kullanımı yer alır. Yeni bilimsel çalışmalar, bu yöntemlerin geleneksel tarıma göre birim ürün başına daha az hem karbon hem de su ayak izine sahip olduğunu kanıtlamaktadır. Bu alandaki keşifler, gıda güvenliği ile iklim ve su güvenliğini birlikte çözme potansiyeli sunmaktadır (Control Union, 2024).
- **Döngüsel Biyoekonomi: Atıklardan Değer Yaratarak Hem Karbon Hem de Su Ayak İzini Azaltan Entegre Sistemler:** Döngüsel biyoekonomi, tarımsal ve endüstriyel organik atıkları (örneğin, gıda atıkları, tarımsal kalıntılar, atık su çamuru) biyoenerjiye, biyoplastiklere, biyoyakıtlara veya besin maddelerine dönüştüren sistemlerdir. Bu yaklaşım, hem atıkların bertarafından kaynaklanan metan emisyonlarını (karbon ayak izi azaltımı) önler hem de su arıtma süreçlerinde enerji ve kimyasal kullanımını optimize eder. Örneğin, atık su arıtma tesislerinden biyogaz üretimi, hem enerji hem de su geri kazanımını sağlar. Ayrıca, alglerden biyoyakıt üretimi gibi yenilikçi yaklaşımlar, atık suyu kullanarak karbonu bağlamakta ve değerli ürünler elde etmektedir. Bu entegre sistemler, kaynak verimliliğini artırarak genel çevresel ayak izini önemli ölçüde düşürmektedir (Ellen MacArthur Foundation, 2023).

3.4. Entegre Çözüm Önerileri ve Politika Geliştirme

- **Ortak Fayda Sağlayan (Co-benefit) Projeler ve Politikalar:** İklim değişikliği ve su yönetimi stratejileri, birbirlerini güçlendirecek şekilde tasarlanmalıdır. Örneğin, ormanların ve sulak alanların korunması ve restorasyonu hem karbon sekestrasyonuna katkıda bulunur hem de su kaynaklarını korur ve taşkınları önler.
- **Nexus Yaklaşımını Temel Alan Bölgesel ve Ulusal Planlama:** Hükümetler, su, enerji ve gıda politikalarını ayrı ayrı ele almak yerine, bu sektörlerin entegre bir şekilde yönetildiği ulusal ve bölgesel planlar geliştirmelidir. Bu, kaynak tahsisinde daha verimli kararlar alınmasını ve olası çatışmaların önlenmesini sağlar.
- **Paydaş Katılımı:** Sürdürülebilir entegre çözümler için çiftçiler, sanayiciler, yerel yönetimler, sivil toplum kuruluşları ve araştırmacılar dahil tüm paydaşların sürece dahil edilmesi önemlidir (Hoff, 2011).

4. GELECEK PERSPEKTİFLERİ, ZORLUKLAR VE FIRSATLAR

Karbon ve su ayak izi kavramları, insanlığın gezegen üzerindeki etkisini anlamak ve azaltmak için kritik araçlar sunsa da, gelecekte bu alanlarda hem büyük zorluklar hem de heyecan verici fırsatlar bulunmaktadır (IPCC, 2023).

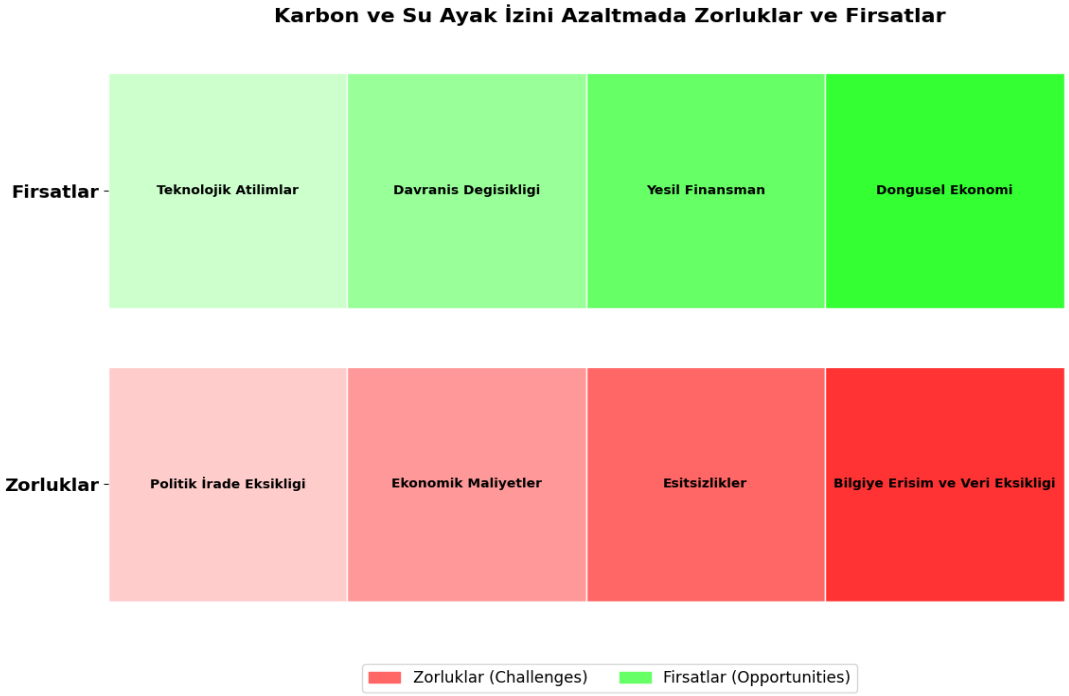
4.1. Teknolojik Atılımların Potansiyeli

Gelecek, yapay zeka (AI), biyoteknoloji, nanoteknoloji, gelişmiş malzemeler ve genetik mühendisliği gibi alanlardaki hızlı ilerlemelerle şekillenecektir.

- **Yapay Zeka ve Büyük Veri:** AI, enerji şebekelerinin gerçek zamanlı optimizasyonundan, tarımsal sulamanın hassas kontrolüne, tedarik zinciri emisyonlarının şeffaf izlenmesinden, su kirliliği tespiti ve arıtma süreçlerinin otomatik yönetimine kadar geniş bir yelpazede çevresel faydalar sağlayabilir. Özellikle AI

destekli "dijital ikizler" teknolojisi, karmaşık sistemlerin simülasyonu ve optimizasyonu için yeni kapılar açmaktadır (GE Vernova, 2025).

- **Biyoteknoloji ve Genetik Mühendisliği:** Daha az su ve gübre gerektiren, iklim değişikliğine (kuraklık, sıcaklık stresi) dayanıklı bitki türlerinin geliştirilmesi, biyoenerji üretiminde verimliliğin artırılması ve biyo-bazlı malzemelerin (plastik yerine) geliştirilmesi yoluyla karbon ve su ayak izlerinin azaltılmasına önemli katkılar sunabilir. Örneğin, karbonu daha verimli bağlayabilen veya su kıtlığına daha dirençli mahsuller genetik olarak tasarlanabilir (Control Union, 2024).
- **Nanoteknoloji:** Geliştirilmiş su filtreleme membranları, daha verimli güneş pilleri ve enerji depolama çözümleri (nanopartikül bazlı bataryalar) nanoteknolojinin çevresel uygulamalarına örnek teşkil etmektedir. Grafen bazlı filtreler, su arıtımında devrim yaratma potansiyeline sahiptir (Northwestern University, 2023).



Şekil 9. Karbon ve Su ayak izi azaltmada zorluklar ve fırsatlar

4.2. Davranış Değişikliği ve Toplumsal Farkındalığın Rolü

Teknolojik çözümler kritik olsa da, bireysel ve toplumsal davranış değişiklikleri olmadan sürdürülebilir bir geleceğe ulaşılamaz. Tüketim alışkanlıklarının gözden geçirilmesi (daha az et tüketimi, yerel ve mevsimsel ürün tercihi), enerji verimliliğinin artırılması (evde ve işte), su tasarrufu ve atıkların azaltılması, her bireyin sorumluluğudur. Eğitimin, farkındalık kampanyalarının ve yeşil yaşam tarzlarının teşvik edilmesi, bu dönüşümde merkezi bir rol oynamaktadır (Water Footprint Network, 2024).

4.3. Yeşil Finansman ve Sürdürülebilir Yatırımlar

Sürdürülebilir projelere yönelik finansman, küresel karbon ve su ayak izini azaltma çabalarının temelini oluşturur. Yeşil tahviller, sürdürülebilir yatırım fonları, karbon kredisi piyasaları ve iklim finansmanı mekanizmaları, düşük karbonlu ve suya duyarlı ekonomiye geçişi hızlandırabilir. ESG (Çevresel, Sosyal, Yönetişim) kriterlerinin yatırım kararlarında daha fazla

yer alması, sermayenin sürdürülebilir alanlara yönlendirilmesine katkıda bulunmaktadır (European Commission, 2023).

4.4. Karşılaşılabilecek Engeller

- **Politik İrade Eksikliği:** Çevresel sorunların ciddiyetine rağmen, bazı ülkelerde kısa vadeli ekonomik çıkarların uzun vadeli çevresel sürdürülebilirlik hedeflerinin önüne geçmesi büyük bir engeldir.
- **Ekonomik Maliyetler:** Yeşil teknolojilerin ve sürdürülebilir altyapının ilk yatırım maliyetleri yüksek olabilir. Bu, özellikle gelişmekte olan ülkeler için önemli bir zorluk teşkil eder.
- **Eşitsizlikler:** İklim değişikliği ve su kıtlığından en çok etkilenenler genellikle en az sorumluluğu olan yoksul ve savunmasız topluluklardır. Çözümlerin adil bir şekilde dağıtılması ve "adil geçiş" (just transition) sağlanması gereklidir.
- **Bilgiye Erişim ve Veri Eksikliği:** Özellikle tedarik zincirlerindeki Kapsam 3 emisyonları ve küresel su ayak izi verilerinin güvenilirliği ve tamlığı hala iyileştirilmesi gereken bir alandır (GHG Protocol, 2021).

Tablo2. Karbon ve Su Ayak İzi Azaltımı İçin İnovatif Teknolojiler

Teknoloji Alanı	Karbon Ayak İzi Azaltımı	Su Ayak İzi Azaltımı
Yenilenebilir Enerji	Fosil yakıt kullanımının azaltılması, güneş, rüzgar, hidroelektrik enerji üretimi	Termik santral soğutma ihtiyacının azaltılması
Karbon Yakalama ve Depolama (CCUS)	Atmosferden CO2'nin doğrudan yakalanması ve depolanması	Sınırlı doğrudan etki, bazı su yoğun endüstriyel süreçlerin optimizasyonu
Akıllı Sulama Sistemleri	Su pompalaması için enerji kullanımının azaltılması	%50'ye varan oranlarda sulama suyu tasarrufu
Döngüsel Ekonomi Modelleri	Hammadde çıkarma ve üretim ihtiyacının azaltılması	Su tüketen üretim süreçlerinin azaltılması ve su verimliliğinin artırılması
İleri Membran Teknolojileri	Su arıtma ve desalinasyon için enerji ihtiyacının azaltılması	Atık suyun geri kazanımı ve tuzlu suyun içme suyuna dönüştürülmesi
Yapay Zeka Destekli Optimizasyon	Enerji şebekelerinin, endüstriyel süreçlerin ve tedarik zincirlerinin optimizasyonu	Su kayıplarının tespiti, su dağıtım sistemlerinin ve arıtma tesislerinin optimizasyonu
Rejeneratif Tarım	Toprak karbon sekestrasyonu ve daha az gübre/yakıt kullanımı	Toprağın su tutma kapasitesinin artırılmasıyla sulama ihtiyacının azaltılması

5. SONUÇ VE EYLEM ÇAĞRISI

Bu seminer araştırması, karbon ve su ayak izlerinin gezegenimizin karşı karşıya olduğu en kritik çevresel zorluklar olduğunu ve birbirleriyle karmaşık bir şekilde bağlantılı olduklarını ortaya koymuştur. İklim değişikliği ve su kıtlığı, sadece çevresel birer mesele olmanın ötesinde, ekonomik istikrarı, sosyal adaleti ve insan sağlığını doğrudan etkileyen küresel krizlerdir.

Araştırmamız, bu alanlardaki en son bilimsel keşifleri ve teknolojik yenilikleri vurgulayarak, sorunların boyutunu daha iyi anlamamızı ve çözüm potansiyellerini görmemizi sağlamıştır. Atmosferik CO2 konsantrasyonlarındaki rekor seviyeler, çözülen permafrostun yarattığı geri besleme döngüleri, dijitalleşmenin artan karbon ayak izi gibi "yeni bilgiler ve keşifler", acil eylem ihtiyacını bir kez daha gözler önüne sermektedir. Benzer şekilde, yeraltı suyu tükenmesinin uydu tabanlı izlenmesi, mikroplastiklerin su kaynakları üzerindeki etkileri

ve iklim değişikliğinin su döngüsündeki beklenmedik değişimleri, su yönetimi konusunda devrim niteliğinde yaklaşımlara duyulan ihtiyacı pekiştirmektedir.

Ancak umut vardır. Yenilenebilir enerji teknolojilerindeki çığır açan ilerlemeler (füzyon enerjisi araştırmaları, yeşil hidrojen), karbon yakalama ve depolama teknolojileri, döngüsel ekonomi modelleri ve yapay zeka destekli optimizasyonlar, karbon ayak izimizi azaltmak için güçlü araçlar sunmaktadır. Su alanında ise, ileri arıtma ve geri kazanım teknolojileri, akıllı sulama sistemleri, su verimli endüstriyel prosesler ve tuzdan arındırma çözümleri, su kıtlığına karşı mücadelede önemli adımlar atmamızı sağlamaktadır.

En önemlisi, karbon ve su ayak izlerinin kesiştiği alanlarda, "mavi karbon" ekosistemlerinin korunması, rejeneratif tarımın yaygınlaşması ve döngüsel biyoekonomi modellerinin benimsenmesi gibi "ortak fayda" sağlayan entegre çözümler, her iki krizi birden ele almamıza olanak tanımaktadır. Su-Enerji-Gıda Bağlantısı (Nexus) yaklaşımı, kaynak yönetiminde parçalı değil, bütüncül bir bakış açısının ne kadar kritik olduğunu göstermektedir.

5.1. Eylem Çağrısı:

Bu kapsamlı araştırma, gezegenimizin geleceği için acil, kararlı ve koordineli eylem çağrısı yapmaktadır:

1. **Bireysel Düzeyde:** Tüketim alışkanlıklarımızı gözden geçirelim. Enerji ve su tasarrufuna özen gösterelim. Daha az et tüketelim, yerel ve mevsimsel ürünleri tercih edelim. Geri dönüşüm ve atık azaltımına katkıda bulunalım. Politikaları ve şirketleri sürdürülebilirlik yönünde değişmeye teşvik edelim.
2. **Kurumsal Düzeyde:** Şirketler, sadece Kapsam 1 ve 2 değil, tüm tedarik zincirini kapsayan Kapsam 3 emisyonları ve su ayak izlerini şeffaf bir şekilde ölçmeli ve azaltma hedefleri belirlemelidir. Bilim Temelli Hedefler Girişimi (SBTi) gibi standartlara uyum sağlamalı, döngüsel ekonomi prensiplerini iş modellerine entegre etmeli ve su-pozitif yaklaşımlar benimsemelidir. Yeşil teknolojilere yatırım yapmalı ve yenilikçi çözümleri desteklemelidirler.
3. **Hükümet ve Politika Düzeyinde:** Paris Anlaşması ve diğer uluslararası iklim/su anlaşmalarına tam uyum sağlamalı, iddialı Ulusal Olarak Belirlenmiş Katkıları (NDC'ler) güncellemeli ve uygulamalıdır. Karbon fiyatlandırma mekanizmalarını (ETS, karbon vergisi) etkin bir şekilde kullanmalı, yenilenebilir enerji ve su verimliliği teknolojilerine teşvikler sunmalıdır. Su-Enerji-Gıda Bağlantısı temelinde entegre kaynak yönetimi politikaları geliştirmeli ve uygulamalıdır. İklim değişikliği ve su kıtlığından en çok etkilenen savunmasız topluluklara adil bir geçiş sağlamak için sosyal politikalar tasarlamalıdır.

Gezegenimiz, ortak evimizdir ve onu korumak hepimizin sorumluluğudur. Bilimsel bilgiye dayalı, cesur ve yenilikçi adımlar atarak, gelecek nesiller için yaşanabilir, sürdürülebilir ve adil bir dünya inşa edebiliriz. Bu araştırma, bu yolda atılacak adımlar için bir rehber ve bir ilham kaynağı olmayı umut etmektedir. Zaman daralıyor, eylem şimdi başlamalıdır.

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ERKEN ÇOCUKLUK DÖNEMİNDE BİYOFONİK SESLERİN KULLANIMI VE ÖNEMİ

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Özet

Biyofonik ses kavramı, tabiatta organizmalar tarafından oluşturulan (kuş cıvıltısı, aslan kükremesi, kuzuların, böceklerin, insan dışındaki canlıların çıkardığı sesler) ve ekosistemin bir ögesi olan seslerin ifadesi için kullanılmaktadır. Bu sesler, işitsel çevreyi oluşturan bir bileşen olarak kabul görmüş ve çocuklarda çevre farkındalığını, odaklanma derecesini, stres regülasyonunu, öğrenmeye açık olmayı da kapsayan birçok gelişim özelliği konusunda olumlu etkilerinin olduğu belirtilmektedir. Erken çocukluk evresi, nöral plastisitenin üst düzey olduğu, duyusal uyarıcılara açık ve öğrenme potansiyelinin azami olduğu gelişimsel bir dönemdir. Bu dönem süresince işitsel çevrenin niteliği, çocukların okul başarılarını etkilerken, psikolojik ve sosyal gelişimine yönelik kritik öneme sahiptir. Alan yazında, biyofonik seslerin tabii (doğa gezisi, açık alan faaliyetleri) veya eğitimde teknoloji kullanımı vasıtasıyla yapay (çevrim içi yazılımlar, işitsel kitaplar) olarak kullanılmasının çocukların gelişiminin desteklenmesine yardımcı olduğu yer almaktadır. Bu çalışma bir derleme çalışması olup, biyofonik seslerin erken çocukluk dönemindeki çocukların duyusal, bilişsel ve duygusal gelişimlerine ilişkin etkileri incelenmiştir. Çalışmada ayrıca biyofonik seslerin bireyler üzerindeki etkileri, eğitsel çevreye entegre edilmesi, eğitimde kullanılmasının yansımalarına da yer verilmiştir. Bu kapsamda, biyofonik seslerin erken çocukluk eğitiminde bir bileşen olarak sistemli bir biçimde incelenmesi, eğitim faaliyetlerinde daha yaygın kullanılmasını sağlayacaktır.

Giriş

Biyofonik/biyoakustik sesler, tabii ortamda yaşam süren organizmaların ürettiği, insan etkisi bulunmadan oluşturulan akustik sinyalleri ifade etmektedir. Kuş cıvıltısı, böcek vızıltısı, kurbağa vıraklaması, koyun melemesi gibi hayvanların seslerini içermektedir. Biyofoni, öncelikle akustik ekoloji alanında kavram haline gelmiş ve tabii çevreyle işitsel algı arasında bulunan bağın bilimsel açıdan incelenmesine imkân tanımıştır. Biyofoni, doğa insanların ruhsal, zihinsel ve bedensel halleri üstünde yoğun etkiler bırakabilmektedir. Bilhassa erken çocukluk döneminin, nörogelişim açısından çocukların duyularının hızlı gelişen, çevredeki uyarıcılara açık ve öğrenmenin üst olduğu kritik bir evre kabul edildiği bilinir. Bu dönem içinde işitsel çevre, dil gelişimini, duygusal dengeyi, dikkat süresini, stres yönetimini ve sosyal etkileşimi desteklemektedir. Alan yazında, çocukların doğal ses ortamlarıyla etkileşimde olmalarının, öz düzenlemeyi, öğrenme motivasyonunu artırdığı ve yaratıcılıklarının gelişmesine katkı sağladığı belirtilmektedir. Duyu bütünleme çalışmalarında da önemi bulunmakta olup, düzensizliğe yönelik düşük toleransı olan çocuklarda rahatlatıcı etkilerinin olduğu, psikolojik dayanıklılığın artmasına fayda sağladığı bilinmektedir. Pedagojik ortamlar yalnızca görme duyusu için değil, işitme açısından da zenginleştirilmelidir. Okul öncesi eğitim sınıflarında biyofonik sesler yer aldığında, çevre farkındalığı ve doğayla bağı güçlenecektir. Sessiz gözlemin ve doğa etkileşiminin amacı da biyofonik seslerin kullanımıyla temelde aynıdır. Canlıların çevresel uyaranlara verdiği tepki anne karnında başlamaktadır. Dünyayla etkileşim kurma yollarından biri olmasından dolayı, tabiatın bir parçası olan insanları tabiatta türetilen seslerle bütünleşmesi, birçok alanda etkili bulunmaktadır.

1. Biyofonik Ses Nedir?

Ses, uyum içeren titreşimlerin bir araya gelmesi şeklinde tanımlanmakta ve birçok canlı iletişim için kullanmaktadır. Daha kapsamlı çerçevede bir ritm, tempo ve ahengi anımsatan canlı veya cansızların çıkardığı sesler, kâinatın müziği kabul edilebilir (rüzgârın, suyun, dalganın sesi, kuş cıvıltıları vs) (Koç vd., 2016). İnsan ve çevresel seslerin birbirinden ayrıldığı bir yaklaşım, duyusal farkındalık ile çevresel bilinci teşvik ederek duyusal temelli öğrenmenin etkilerini göstermektedir (Heintzman ve Hélène Deacon, 2024). Araştırmalar doğa sesiyle temas kurmanın sempatik sinir sistemini daha hızlı iyileştirdiğini göstermektedir (Alvarsson, Wiens ve Nilsson, 2010).

Ülkemizde okul öncesi çocukların ziyaretine uygun örnek biyofonik ses dinleme alanları:

- **Atatürk Arboretumu (İstanbul- Sarıyer):** Çocuklara kuş cıvıltılarını dinleyebilecekleri güvenli bir ortam sunmaktadır.
- **Eymir Gölü (Ankara):** Su kuşlarının, sazlık böceklerinin sesleriyle su ekosisteminin öğrenilmesi için fırsat yaratır.
- **Kuğulu Park (Ankara- Çankaya):** Kuğuların, ördeklerin, kuşların, kedilerin, sinekler ve böceklerin sesleri ile biyofonik seslerle iç içe olmak için eşsiz bir fırsat sunmaktadır.
- **Sazova Bilim Kültür ve Sanat Parkı (Eskişehir):** Ördekler ve çeşitli kuşların seslerine yönelik ayırt etmek etkinlikleri yapmak için uygundur.
- **Karagöl Tabiat Parkı (İzmir- Menemen):** Kurbağaların, kuşların, göl ekosisteminin seslerini tanımak için olanak tanır.
- **Nezahat Gökyiğit Botanik Bahçesi (İstanbul- Ataşehir):** Arılar, kuşlar, böcekler tarafından üretilen seslerle benzer farklı türde hayvanların ses karşılaştırılması yapılabilir.
- **Kent Ormanı (Bursa- Nilüfer):** Doğal orman kuşlarının sesleriyle duyusal gelişime katkı sağlamaktadır.
- **Atakum Kent Ormanı (Samsun):** Kuşlar, cırcır böcekleri ile orman ekosisteminde yer alan hayvanlara yönelik biyofonik ses çalışmalarına olanak tanır.
- **Acarlar Longozu (Sakarya- Karasu):** Kurbağalar, su kuşları, sazlık böcekleri vb. habitata ait hayvan aracılığıyla çocuklarla ççeşitli çalışmalar yapmak mümkün olmaktadır.

- **Hacılar Ormanları / Talas Orman Parkı (Kayseri):** Serçe ve saka kuşları, böcek sesleri eşliğinde dinleme ve imgeleme çalışmalarına uygun bulunmaktadır.
- **Sultan Sazlığı Milli Parkı (Yahyalı, Develi, Yeşilhisar):** 300'den fazla kuş türüne (pelikan, turna, balıkçıl) ve sazlıklarda yaşam süren diğer canlılara ev sahipliği yapan bu park, çocuklar için biyofonik seslerle etkileşim kurmak için çok önemli bir fırsat sunmaktadır.

Yanı sıra hayvanların doğal ortamlarından koparılarak sergilendiği, bu durumun sona ermesi için birçok uzmanın ziyareti önermediği hayvanat bahçeleri, hayvan parkları da biyofonik seslerin dinlenebilmesi için tercih edilebilmektedir. Çocukların işitsel algılarını geliştirmek, hayvan seslerini ayırt etme, benzer/farklı özelliklerini bilme gibi beceriler için evcil hayvanlar ve çiftlik hayvanlarının yanında vahşi hayvanların da seslerini eğitim ortamına dahil etmek gerekmektedir.

1. Erken Çocukluk Eğitiminde Gelişim Alanları Bağlamında Biyofonik Seslerin Kullanımı

Çocuklar, bireysel niteliklerle hayata gelmekte ve içinde yetiştiği ortamla etkileşim içinde toplumun bir parçası olmaktadırlar. Okul öncesi dönemi de içerisinde barındıran, erken çocukluk döneminde çocukların gelişim alanlarının tümü hızlı bir biçimde gelişim gösterir. Eğitimin anne karnında başladığı, doğumla beraber aile ve çevrede oluşan sosyal yaşamın içinde devam ettiği kabul edilir. Gelişimde en kritik evre olarak tanınan yaşamın ilk yılları, bireylerin eğitim sürecinde de en hassas dönemi oluşturmaktadır (Demirci ve Mertoğlu, 2024). Erken çocukluk eğitiminde işitsel deneyimlerin bütünleştirilmesi, duyusal tabanlı öğrenmenin çocukların gelişimini bütüncül olarak destekleme potansiyelini vurgulamaktadır. Hem insan hem de çevresel seslerin kullanıldığı kaynaklar, duygusal düzenlemeyi, yaratıcılığı, çevresel farkındalığı ve pratik yaşam becerilerini geliştirmek için benzersiz bir platform sağlamaktadır. Bu kaynaklar duyusal ve bilişsel öğrenmeyi zenginleştirmenin yanı sıra, Montessori ilkeleri, keşif becerisi, eleştirel düşünme ve öz farkındalığı teşvik etme gibi gelişimsel ideallerle de uyumludur. Yenilikçi bir eğitim aracı olarak, bu yöntemler işitsel öğrenmenin çocukların bilişsel ve duygusal gelişimi üzerindeki uzun vadeli etkileri hakkında daha fazla araştırma için yollar açmaktadır (Zubaedah, 2024). Bireyin çevrede olanların farkına varması için duyduğu sesi algılaması, sesleri tanıması ve ayırt etmesi oldukça önemli olmaktadır (Demircioğlu ve Kavgacı, 2020; Courtade, Spooner ve Browder, 2007; Therrien, Taylor, Hosp, Kaldenberg ve Gorsh, 2011).

Görsel 1. Biyofonik seslerle etkileşimde olan çocuklar *(Görsel yapay zekâ aracılığıyla yazarlar tarafından oluşturulmuştur.)*

Ayrıca Dikkat Restorasyon Teorisine göre de gün içinde gerçekleşen faaliyetler ve stres ortamları insanlarda ruhsal ve zihinsel yorgunluğa neden olmaktadır. Teori, "uzaklaşma",

"büyülenme", "uyum/ahenk" ve "uyumluluk" özellikleri bulunan doğal yeşil ortamların stres ve ruh sağlığı yorgunluğuna karşın restoratif (onarıcı) etki sunduğunu belirtmektedir (Akpınar ve Lafvermez, 2016). Yeşil ortamlarda, tabiatta bulunmanın bir diğer getirisi de tabiatta bulunan biyofonik seslerle etkileşimde olmaktır. Ayrıca Shinrin- Yoku (orman banyosu), ilk defa 1982'de Japonya devleti aracılığıyla da desteklenmiş, bu şekilde uygulamaya geçilmiştir. İnsanların doğaya duyduğu ihtiyaç var oluştan gelmekte olup, doğayla olan etkileşimin sonucunda kendini onarmak ve daha iyi hissetmek mümkün olmaktadır (Ardahanlıoğlu, 2023; Kaplan ve Kaplan, 1989). Beş duyu organı işe koşularak yapılan Shinrin-Yoku'nun işitme kategorisinde, yapraklar arasında esen rüzgârın, doğal ortamda akan suyun yanı sıra kuşların cıvıltıları gibi ormanda türeyen işitsel uyarımın bireyde ruhsal ve bedensel açıdan gevşeme sağladığı ve stresten kurtulma konusunda yardımcı olduğu bilinmektedir (Annerstedt, 2013; Franko, 2017; Joe, 2019; Ochiai, 2020; Ardahanlıoğlu, 2023).

Görsel 2. Eğitim ortamlarında biyofonik seslerin kullanımı ile ilgili örnek resimler *(Görsel yapay zekâ aracılığıyla yazarlar tarafından oluşturulmuştur.)*

Her hayvana erişim mümkün olmayabilir yahut bu durum tehlikeye yol açabilir. Bu nedenle teknolojik gelişmelerden faydalanmak, eğitimde teknolojik ders materyalleri kullanmak önem kazanmaktadır. Teknolojik gelişmeler; sanal gerçeklik (VR), artırılmış gerçeklik (AR) ve yapay zekâ (AI) aracılığıyla çocukların temas imkânı bulmadığı hayvanlarla ve sesleriyle etkileşim kurmaları mümkündür.

Görsel 3. AR destekli Animal 4D uygulaması *(Karekod ile uygulama içeriğine erişim sağlayabilirsiniz.)*

Çocuklara uygun eğitim içerikleriyle hazırlanmış AR destekli mobil uygulamalar, hayvanların gerçek sesleriyle hazırlanması sebebiyle çocuklara biyofonik sesleri istedikleri sürece dinleme,

eğitimcilere ise biyofonik sesleri eğitim ortamında kullanma imkânı sunmaktadır. Yanı sıra seslerdeki nitelik farklılıklarının da göz önüne alınması gerekmektedir. Yüksek frekans içeren, düzenli olmayan ya da insanlar tarafından türetilen seslerin (antropofoni) çocuklarda dikkat dağıtan, rahatsız edebilen veya kaygı artıran etkileri olduğu belirtilmektedir. Beraberinde ritim içeren ve düzenli yapısı olan biyofonik seslerin bilişsel gelişime katkı sağladığı, dikkat süresini artırdığı, eğitim için engelleyici unsur olan günlük yaşam stresörlerinin etkisini azalttığı ifade edilmektedir.

Sonuç

Erken çocukluk dönemi, tüm gelişim alanlarının temelinin atıldığı kritik bir dönem kabul edilir. Bu süreçte çevreden gelen uyarıcıların özelliği, çocukların öğrenme potansiyellerini ve doğa ile kurulan bağlantıyı dolaysız etkilemektedir. Bu doğrultuda biyofonik seslerin erken çocukluk eğitiminde kullanılması, duyusal farkındalıkların artması, dikkat ve konsantrasyon becerilerinin geliştirilmesi ve doğayla özdeşim kurmalarının desteklenmesini sağlamaktadır. Teknoloji destekli öğrenme ortamları içerisinde biyofonik seslerin, AR, VR, dijital içerik ve materyallerle entegre edilerek, çocuklarda çoklu duyu hareketini sağlayan, interaktif ve kalıcı öğrenmeyi içeren deneyimler ortaya koymaktadır. Bilhassa tabiata sınırlı erişim imkânı bulunan kent çocukları için bu seslerle dijital temaslar kurulması, doğa eğitimi için tazmin edici bir rol oynamıştır. Yanı sıra biyofonik seslerin, yaratıcı oyun ortamlarını zenginleştirmede, etkili hikâye anlatımı ve fen doğa temelindeki etkinlikler içerisinde, sınaî öğrenme biçimine destek olan bir aracı şeklinde kullanılabilmektedir. Son olarak, biyofonik sesler erken çocukluk eğitimi içerisine sistemli bir şekilde bütünleştirildiğinde, çocuklarda çevre duyarlılığı geliştirilmesi, bilişsel gelişimlerinin kapsayıcı desteklenmesi ve teknolojinin etkin biçimde kullanılmasıyla öğrenme süreçleri içerisine doğa temelli bir boyut kazandırılmasına imkân tanımaktadır. Nitekim, öğretmenlerin ve eğiticilerin biyofonik sesleri pedagojik anlamda etkin kullanabilmek adına gereken dijital materyal desteği ve öğretmen eğitimlerini yaygınlaştırma konularının yer aldığını belirtilmektedir.

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OKUL ÖNCESİNDE DOĞA TABANLI MATERYALLERİN YAPAY ZEKÂ DESTEKLİ ÖĞRENME DENEYİMLERİNE ENTEGRASYONU

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Özet

Geleneksel doğa temelli materyallerin, okul öncesi eğitim içerisinde, zihinsel, duyusal ve motor gelişimi destekleyen vazgeçilmez araçlardan olduğu bilinmektedir. Fakat dijital çağ eğitim üzerinde de etkili olup, mevcut materyallerde, teknolojik gelişmeler ile tekrar işlevlendirme yapılması gerekliliği gündeme gelmiştir. Bu anlamda, yapay zekâ (YZ) teknolojilerini okul öncesi eğitim ortamlarına entegre etmek, çocukların bireyselliği temel alan öğrenme biçimlerine elverişli, bireyselleştirilmiş ve etkileşim içeren deneyimlerin sunulması potansiyeli içermektedir. Bu çalışmada, okul öncesi eğitim etkinliklerinde yararlanılan doğa tabanlı materyallerin, yapay zekâ ile zenginleştirilmesi sonucu nasıl daha etkin öğrenme araçlarına dönüştürülebileceği konusunu alan yazın taramasıyla incelenmiş ve bu doğrultuda örnek modeller hazırlanmıştır. Çalışma çerçevesinde, yapay zekâ destekli içeriklerin, doğa tabanlı materyaller ile bütünleştirilmesi amacıyla örnek modeller geliştirilmiştir. Bu öneriler, okul öncesi eğitimde kullanılacak yeni nesil materyal tasarımı fırsatlarını gündeme getirmeyi amaçlamaktadır. Çalışmanın amacı doğrultusunda, tasarım tabanlı araştırma yöntemi kullanılmıştır. YZ destekli uygulamaların, özellikle duyusal gelişime, odaklanmaya, problem çözmeye ve yaratıcılık konularına etkileri ele alınmıştır. Çalışma doğa temelli geleneksel yaratıcı materyallerin hazırlanması ve materyallere yapay desteği oluşturulması olmak üzere iki aşamadan oluşmaktadır. Bu bağlamda hazırlanan fen ve doğa temelli materyallerin; YZ desteğiyle, QR kod kullanılarak, uygulama ve animasyon videoları, materyal konusuna özgü şarkıları oluşturulmuştur. Materyalin YZ destekli versiyonu, bir sosyal medya platformu olan YouTube'a yüklenmiş olup, materyale yerleştirilmiş olan kare kod okutularak ulaşılması sağlanmıştır. Bu çalışmanın, Türkiye'de okul öncesi eğitimde sıklıkla yer alan doğa temelli materyallerin pedagojik dayanaklarını koruma koşulu ile modern YZ teknolojilerine uyumlu hâle getirilebileceğini ve bu sayede çocuğun çevresiyle etkileşimini çok boyutlu bir şekilde artırmasına, çoklu duyu ve gelişim alanına yönelik olmasına, eğitimde YZ kullanılmasını artırarak 21. yy becerilerine sahip bireyler yetiştirilmesine olanak sağlayabileceği düşünülmektedir.

GİRİŞ

Okul öncesi eğitim dönemi, çocukların çevreleriyle etkileşim kurduğu, keşfetme konusunda içsel motivasyonlarının en yüksek olduğu gelişim evresidir. Bu evrede öğrenmenin kalıcı olması, çocukların aktif katılım sağlaması ve birden fazla duyu alanına uygun materyaller ile desteklenmesini gerektirmektedir. Bu anlamda doğa konulu 3D materyallerin, çocuklarda çevre farkındalığını artırdığı, motor, zihinsel ve sosyal becerilerini desteklediği alan yazında yer almaktadır. Günümüzde gelişen teknoloji doğrultusunda, eğitim materyallerinin de dijital araçlar ile uyumlandırılması gerektirmekte, bu durumda yapay zekâ destekli etkinlik ve materyallerin okul öncesi eğitim içerisinde kullanılması açısından yeni imkanlar doğmaktadır. Doğa konulu, doğa tabanlı materyallerin okul öncesi eğitimde kullanılması, çocukların doğa ile etkileşimine katkı sağlarken öğrenme ortamına sürdürülebilirlik, çocuklara zihinsel esneklik, problem çözebilme ve eleştirel düşünebilme gibi üst düzey bilişsel becerilerin gelişimini de desteklemektedir. Doğayla ve doğadaki canlılar ve durumlarla her zaman yakın temas kuramayan çocuklar için önemli olan materyaller; çocuklarda duyusal keşifleri teşvik etmekte, yaratıcı oyunlara fırsat vermekte ve çevresel farkındalık geliştirmelerini sağlamaktadır. Ancak çocukların doğayla temas etme fırsatlarının azaldığı günümüz dünyasında, doğa temelli materyalleri teknolojik araçlarla desteklemek, öğrenme ortamlarını daha erişilebilir ve sürdürülebilir hale getirebilir. Yapay zekâ destekli uygulamalar, bu noktada öğretmen ve çocuklara yeni fırsatlar sunar. Örneğin, bir yapay zekâ aracı aracılığıyla oluşturulan çocuk şarkısı, çocuğun gezegenleri daha eğlenceli bir şekilde öğrenmesini sağlayabilir; bir animasyon, hayvanların beslenme döngüsünü somutlaştırarak kalıcı öğrenmeyi destekleyebilir. YZ, çocukların yaşlarına ve gelişim düzeylerine yönelik kişiselleştirilmiş, görsel işitsel yönden zenginleştirilen ve interaktif içerikler sunma, öğrenme aşamasını keyifli ve detaylı hale getirebilme gibi kapasitelere sahiptir. Yapay zekânın, eğitim materyalleri geliştirme aşamasında, hayal edileni kolayca ürüne dönüştürebilme fırsatı sunmasıyla öğretmenlerin ve çocukların yaratıcılıklarına katkıda bulunacağı, çok boyutlu düşünme becerilerinin hızlı somut örneklerle geliştirilebileceği düşünülmektedir. Bu çalışmada, doğa konulu geleneksel materyallerin YZ destekli dijital içerikler ile uyumlandırıldığı, gezegenlere yönelik AI destekli bir şarkı, hayvanların beslenmesine yönelik hazırlanan oyun materyallerinin animasyonla zenginleştirilmesi, sürdürülebilir su tüketimi konulu materyalin videoya dönüştürülmesi gibi somut örnekler ile kalıcı öğrenme desteklenmekte, okul öncesi eğitimde yenilikçi bir öğrenme yaklaşımı sunulmaktadır.

Amaç

Bu çalışmanın amacı, okul öncesi dönem çocuklarına yönelik doğa tabanlı ve doğa konulu geleneksel 3D materyallerin YZ destekli dijital içerikler ile bütünleştirilmesiyle zenginleştirilmesine yönelik tasarım temelli modeller sunmaktır.

Yöntem

Bu çalışmada, okul öncesi eğitim etkinliklerinde yararlanılan doğa tabanlı materyallerin, yapay zekâ ile zenginleştirilmesi sonucu nasıl daha etkin öğrenme araçlarına dönüştürülebileceği konusunu alan yazın taramasıyla incelenmiş ve bu doğrultuda örnek modeller hazırlanmıştır. Çalışma çerçevesinde, yapay zekâ destekli içeriklerin, doğa tabanlı materyaller ile bütünleştirilmesi amacıyla örnek modeller geliştirilmiştir. Bu öneriler, okul öncesi eğitimde kullanılacak yeni nesil materyal tasarımı fırsatlarını gündeme getirmeyi amaçlamaktadır. Çalışmanın amacı doğrultusunda, tasarım tabanlı araştırma yöntemi kullanılmıştır. Çalışma doğa temelli geleneksel yaratıcı materyallerin hazırlanması ve materyallere yapay desteği oluşturulması olmak üzere iki aşamadan oluşmaktadır. Bu bağlamda hazırlanan fen ve doğa temelli materyallerin; YZ desteğiyle, QR kod kullanılarak, uygulama ve animasyon videoları, materyal konusuna özgü şarkıları oluşturulmuştur.

Materyalin YZ destekli versiyonu, bir sosyal medya platformu olan YouTube'a yüklenmiş olup, materyale yerleştirilmiş olan kare kod okutularak ulaşılması sağlanmıştır.

Materyal Geliştirme Aşaması

Yeni pedagojik yaklaşımlar, etkin öğrenmenin nasıl gerçekleşeceği, tasarlanacak eğitim materyallerinin hangi niteliklere sahip olması gerektiği konularında araştırma yapılmasını önemli hale getirmiştir. Öğretmenlerden, öğrencileri öğrenme süreci boyunca desteklemesi, bilişsel stratejilerin ne zaman ve nasıl kullanılacağını belirlemesi, öğrenme cesareti vermesi, öğrencilerin üst düzey düşünme yapıları ile meşgul olmalarını sağlamaları beklenmektedir (Akdeniz ve Özdinç, 2021; Nist, 2000). Dale (1969), Öğretim materyallerinin, eğitim ortamındaki rolleri ve önemine yönelik, bilimsel ilkelere dayalı yaşantı konisi oluşturmuştur. Aşağıda Dale'nin bu konudaki bilimsel ilkelerine yer verilmiştir (Çilenti, 1988; İnan, 2006).

- Öğrenme işine dahil olan duyu organlarının sayısı ne kadar çok olursa o denli kalıcı öğrenme gerçekleşir.
- En verimli öğrenme, bireyin kendi kendine yaparak yaşayarak öğrenmesidir.
- Öğrenilen şeylerin birçoğunu gözler yardımı ile öğrenilir.
- Etkin öğretim soyuttan somuta ve basitten karmaşığa doğru ilerler.

Okul öncesi eğitimin temelini oluşturan Fröbel, çocukların kullanıldığı materyalleri hayatın objektif imgelerini, dünyanın ve yaşantıların esasını yansıtabilecek biçimde tasarlamanın gerekliliğinden bahsetmiştir. Bu nedenle çocuğa sağlanan materyaller; çocuğun gelişimini destekleme, merakını giderme ve bir bütünü parçalara ayırma özelliklerini barındırmalıdır. Fröbel'in çalışmasına temel oluşturan materyaller "yumuşak top, küre-silindir-küp, bölünebilen bir küp ile biçim verme (kesme, kıvırma, katlama)" şeklinde sıralanabilir. Fröbel'in oyun nesnelerinden oluşan yansıma ve örnekler günümüzde birçok modern oyuncakta görülmektedir. Fröbel, materyal seçiminde yalnızca çocuklar değil ebeveynlerin de etkililerinin bulunduğunu savunmuştur. Çünkü materyal seçimiyle ilgilenen ebeveynler zaman içinde çocuğunun ilgi ve becerilerini fark edebilir, çocuğu anlayabilir ve onun için uygun materyalleri belirleyebilirler (Kavak ve Coşkun, 2017; Niemann, 1992). Eğitim materyalleri kullanılmasının faydaları Yalın (2010), tarafından belirtilmiştir. Duman (2013), tarafından aktarılan bu faydalar aşağıda belirtilmiştir. Eğitim materyalleri:

1. Çoklu öğrenme ortamı sağmaktadırlar.
2. Öğrencilerin bireysel gereksinimlerinin karşılanmasına katkıda bulunurlar.
3. İlgi çekerler.
4. Öğrenilenlerin hatırlanmasını kolaylaştırırlar.
5. Soyut bilgileri somutlaştırırlar.
6. Zaman tasarrufu sağlarlar.
7. Güvenli gözlem yapabilme fırsatı verirler.
8. Farklı zamanlarda birbirleriyle tutarlılık gösteren içerik sunulmasına imkân tanırlar.
9. Tekrar tekrar kullanılabilme fırsatı sağlarlar.
10. İçeriğin basitleştirilerek anlaşılmasını kolaylaştırırlar.

Bu doğrultuda alan yazın taraması yapılmış, okul öncesi dönem çocuklarına, eğitim müfredatına uygun materyaller tasarlanmıştır. Geliştirilen materyallerin doğa tabanlı, doğa konulu olması ön koşul olarak belirlenmiştir. Çocukların yaşına, gelişim düzeyine, ilgi, dikkat, keşif, merak, gibi duygularına, öğrenme isteğini desteklemeye yönelik geliştirilen materyaller içerisinden örnek modeller seçilmiş, yapay zekâ desteği için hazır hale getirilmiştir.

Yapay Zekâ Desteği Aşaması

Yapay zekâ; insanvari davranışlar sergileme, sayısal mantık desteği, hareket, konuşma ve ses algılama gibi birçok yeteneği bünyesinde barındırmaktadır. Bu doğrultuda yazılım ve donanım sistemleri bulunmaktadır. Yapay zekâ, canlı bir organizmadan faydalanmadan, yapay araçlarla oluşturulmuş ve insanvari davranışlar ve hareketler sergileyerek makinelere özgü

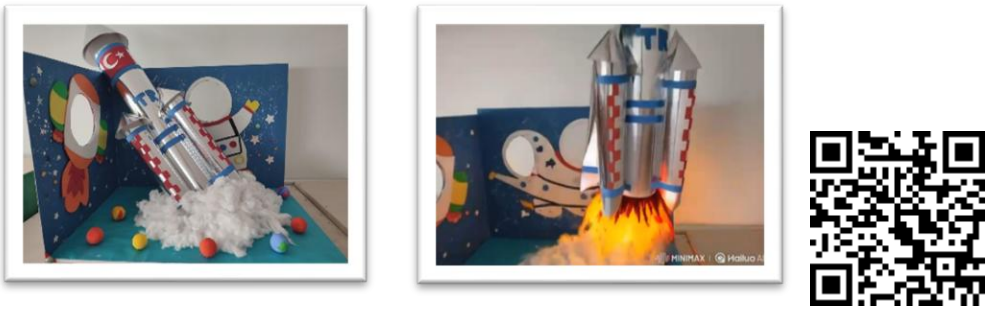
çalışma sistemi ile çalışan teknolojik bir niteliktir. İnsan türüne özgü hisleri hissedebilme, davranışları öngörebilme, karar verebilme gibi niteliklere sahip robotlar şeklinde tanımlanabilir. Bilgisayar teknolojileri ilk çıktığı evrelerde, "Makineler düşünebilir mi?'' sorusu Alan Mathison tarafından araştırılarak bu makinelere yönelik çalışmalar yapılmaya başlanmıştır. II. Dünya Savaşı zamanında YZ, askeri silah teknolojilerinin gelişmesi ile ortaya çıkmıştır. Bu gelişmenin bilgisayarların gelişimine yönelik mühim yeniliklerden biri olduğu bilinmektedir (Değirmenci, 2018; Sucu ve Ataman 2020). Eğitim teknolojilerinde yaşanan gelişmeler geleneksel eğitim ortamlarının teknoloji destekli eğitim ortamlarına dönüştürülmesini gerekli kılmıştır. Teknoloji, eğitim ortamları içerisinde bireylerin öğrenme oranlarına ve hızlarına destek sağlamanın yanı sıra bilgi ve becerilerini daha etkin bir biçimde kullanmalarına faydalı olmakta, tekrar ve dönüt imkânı da sunmaktadır (Börnert-Ringleb, Casale & Hillenbrand, 2021; Günşen, 2023; Siyam, 2019; Toprakçı, 1996). Bu doğrultuda geliştirilen geleneksel materyaller için öncelikle uygun yapay zekâ desteğine karar verilmiştir. Materyalin etkililiğini ve öğrenmenin kalıcılığını artıracak türde çeşitli modeller hazırlanmıştır. YZ destekli model geliştirme aşamaları aşağıda belirtilmiştir.

1. Geleneksel materyallerin görselleri, her materyal için ayrı belirlenmiş olan çeşitli AI uygulamalarına yüklenmiştir.
2. AI uygulamalarına materyalin işlevi, yaş kitlesi, hedefi ve beklenilen destek ile ilgili komutlar verilmiştir.
3. Örnek modeller kontrol edilmiş, materyalin fonksiyonuna uygunluğu test edilmiştir.
4. Materyalin fonksiyonuna, gelişim hedefine uygun olmayan modeller için yeni komutlar yazılmış, farklı AI uygulamalarında komutlar test edilerek karşılaştırma yapılmıştır.
5. Uygun modeller seçildikten sonra ulaşılabilirliği sağlamak amacıyla MP4 (.mp4) formatında ilgili YouTube hesabına yüklenmiştir.
6. İlgili YouTube linki üzerinden kare kod oluşturulmuş ve materyallerin uygun kısımlarına kare kod eklenmiştir.
7. Kullanıcıların uygun cihazlarından kare kodu okutmaları halinde materyalin YZ destekli versiyonuna ulaşmaları sağlanmıştır.

Materyaller ve Yapay Zekâ Destekli Örnek Modelleri

1. Türk Uzay Roketi

Maket okul öncesi dönem çocukları için Fen Alan Becerileri ve Vatanseverlik değerine yönelik hazırlanmıştır. Materyal çocukların, keşfetme, gözlem yapma, sınıflama, ilişkilendirme, problem çözme ve neden- sonuç ilişkisi kurma becerilerini geliştirmeyi desteklemektedir.



Görsel 1. Türk Uzay Roketi ve Generative AI Çıktısı için QR Kod

Üretken yapay zekâ (Generative AI) modeli ile görselden videoya (image to video) teknolojisi kullanılarak, materyal görselinden video çıktısı (output) üretilmiştir. Video çıktısı için "Animate this cardboard rocket craft as if it is launching into space. Start with a close-up of the rocket sitting on the blue platform, surrounded by colorful planets and cotton clouds. Make the

rocket shake slightly as engines ignite, then produce smoke and fire effects from the bottom as it slowly lifts off. Transition to a scene where the rocket rises through the sky, leaving a trail of smoke behind, eventually disappearing into space. Keep the style consistent with the playful and handmade aesthetic of the original craft, using realistic lighting and motion but preserving the texture of paper, cotton, and cardboard." komutu (prompt) kullanılmıştır. İlgili model materyalin video ile zenginleştirilmiş hali olup roketin fırlatılma anını içermesinden dolayı materyali çocuklar için daha öğretici ve ilgi çekici hale getirmiştir. Video çıktısına (output) Görsel 1'de bulunan karekod okutularak erişim sağlanabilmektedir.

2. Sürdürülebilir Sulama Sistemi

Maket okul öncesi dönem çocukları için Fen Alan Becerileri, Sürdürülebilirlik Okuryazarlığı ve Duyarlılık, Sorumluluk, Tasarruf değerlerine yönelik hazırlanmıştır. Okul öncesi dönem çocuklarında sürdürülebilir çevre farkındalığı geliştirmek hedefiyle tasarlanan materyal, farklı modellerle zenginleştirilmiştir. Üretken yapay zekâ (Generative AI) modeli ile materyalin çalışma prensibini tasvir etmek için komut (prompt) yazılmış ve metinden videoya (text to video) teknolojisi kullanılarak video çıktısı (output) üretilmiştir.

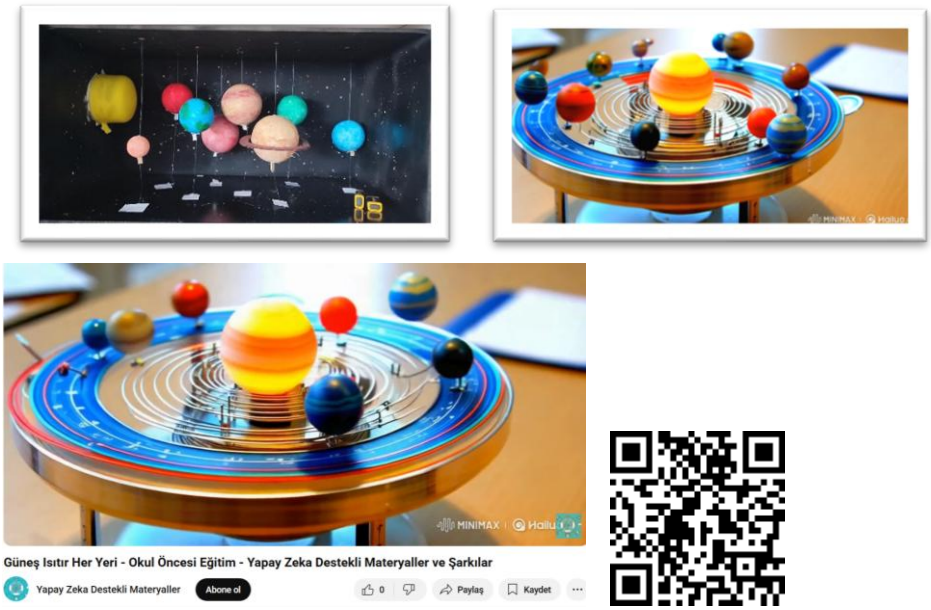
Görsel 2. Sürdürülebilir Sulama Sistemi ve Generative AI Çıktısı için QR Kod

Video çıktısı için "A realistic educational miniature model designed for preschool children. The model demonstrates a simple rainwater harvesting and irrigation system. Rain is falling gently on the roof of a small, toy-like house. A realistic, transparent pipe channels the rainwater from the roof into a horizontally placed plastic bottle next to the house. As the bottle fills up, the collected water is then directed through another small pipe into a miniature garden area, simulating a basic irrigation process. The environment is indoors, set in a classroom, with soft lighting and slightly blurred background details to keep the focus on the model. The materials look handmade yet carefully crafted, using common items like cardboard, plastic bottles, and colored paper. The water movement is smooth and clear, enhancing the realism. This educational setup visually explains how rainwater can be collected and reused, in a way that's engaging and easy to understand for young children." komutu (prompt) kullanılmıştır. Üretilen çıktılar içerisinden uygun modeller seçilmiş, belirlenen en uygun üç model birleştirilip platforma yüklenmiştir. Video çıktısına (output) Görsel 2'de bulunan QR kod ile erişim sağlanabilmektedir. Hazırlanan modellerin çoklu duyu organlarına hitap etmesi sebebiyle öğrenmenin kalıcılığına, çocukların merak ve keşif duygularına, problem çözme ve üst düzey düşünme becerini geliştirmeye yönelik katkı sağlayacağı düşünülmektedir.

3. Güneş Sistemi

Okul öncesi dönem çocukları için Fen Alan Becerilerine yönelik hazırlanan bu maket için iki farklı yapay zekâ modeli kullanılmıştır. Duyusal tabanlı öğrenmenin, eğitim ortamlarında çoklu duyu organlarına uygun materyal kullanmanın öğrenmede kalıcılığı artırdığı alan yazında belirtilmektedir. Bu nedenle materyal için görsel ve işitsel destek kullanılarak; video ve şarkı oluşturulmuştur. İlk olarak üretken yapay zekâ (Generative AI) modeli ile materyalin görseli aracılığıyla güneş sistemi ile ilgili şarkı sözü (image to text) üretilmiş ve metinden sese dönüştürme (text to speech) teknolojisi kullanılarak bir çocuk

şarkısı oluşturulmuştur. Text to speech çıktısı için "A fun, upbeat kids song sung by children, with cheerful melodies, playful instruments like ukulele and bells, and a bright, happy mood, The vocals should sound like a group of kids singing in harmony" komutu kullanılmıştır.



Görsel 3. Güneş Sistemi ve Generative AI Çıktısı için QR Kod

Bir diğer modelde ise iki ayrı çalışma yürütülmüş olup; önce görselden videoya (image to video) teknolojisiyle çıktı (output) alınmış, sonra da materyalin çalışma prensibi aktarılarak metinden videoya (text to video) teknolojisiyle çıktı (output) alınmış, tüm modeller ilgili platforma yüklenmiştir. Text to video çıktısı için "A close-up, detailed shot of a dynamic solar system model designed for educational purposes. The model is placed on a table and features accurately sized, colorful planets orbiting around a bright central sun. Each planet moves smoothly along its orbital path, demonstrating real-time planetary motion. The background is a classroom setting but out of focus; the camera remains tightly focused on the mechanical movements of the planets. The lighting is clear and soft, highlighting the rotation and orbit of each celestial body. The model looks realistic, precise, and visually engaging." komutu (prompt) kullanılmıştır. Görsel 3'te modellerin QR kodu mevcuttur.

4. Toprak Horizonları (Katmanları)

Okul öncesi dönem çocukları için Fen Alan Becerileri ve Bilgi Okuryazarlığına yönelik olan bu geleneksel eğitim materyali, sorgulama, merak etme, bilgiyi somutlaştırma amacıyla hazırlanmıştır. Üretken yapay zekâ (Generative AI) modeli ile materyalin görseli aracılığıyla toprak horizonları ile ilgili şarkı sözü (image to text) üretilmiş ve metinden sese dönüştürme (text to speech) teknolojisi kullanılarak bir çocuk şarkısı oluşturulmuştur.

Görsel 4. Toprak Horizonları ve Generative AI Çıktısı için QR Kod

Text to speech çıktısı için "Fun, upbeat, peaceful, kids song with ukulele, soft percussion, cute child voice, perfect for preschool, education music, clear vocal" komutu (prompt) kullanılmıştır. Görsel 4'te verilen QR kod ile erişim sağlanabilmektedir.

SONUÇ

Doğa temelli/konulu geleneksel materyallerin YZ destekli eğitim ortamlarına entegre edilmesi, okul öncesi eğitim için pedagojik, teknolojik ve yenilikçi bir kazanım şeklinde ele alınmaktadır. Çocukların dokunma, koklama ve deneyimleme ile öğrenme gerçekleştirdiği materyallerin YZ ile zenginleştirilmesi, sadece duyu uyarımını artırmakla kalmaz aynı zamanda bireye özgü öğrenme süreçlerine de olanak tanımaktadır. Eğitimde yapay zekâ desteği ile çocukların hangi materyale ne kadar süre ilgi gösterdiği, hangi sorulara cevap verdiği ve öğrenme aşamasında hangi duyu kanallarını daha etkin kullandığı analiz edilebilmektedir. Bu analizler, öğretmenlerin özgün eğitim planları hazırlaması olanağı ve materyallerin çocukların bireysel öğrenme niteliklerine uygun biçimde uyarlanabilmesini sağlamaktadır. Bu sayede standart materyallerin kullanılması yerine, çocuğa özgü bireysel öğrenme deneyimlerinin sunulması mümkün olmaktadır. Nitekim bu zenginleştirme ve entegrasyon aşaması, çocukların teknoloji okur yazarlığını artırırken, üretken bir bakışla yaklaşmalarını sağlayacaktır. Ancak bu süreç içerisinde pedagojik temeller göz ardı edilmemeli; doğanın kendisinin ve materyallerinin yerini teknolojinin geçmemesi, aksine doğa ve teknoloji iş birliği sağlanması çocukların 21.yy. becerileri geliştirmeleri açısından önemlidir. Sonuç olarak, doğa tabanlı/konulu öğrenme materyallerinin YZ desteği ile yapılandırılarak zenginleştirilmesi, Türkiye'de okul öncesi eğitimde yenilikçi ve sürdürülebilir bir eğitim anlayışı geliştirilmesine katkıda bulunacaktır.

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DFT COMPUTATIONS OF N-ETHYL-P-TOLUENESULFONAMIDE (NEPTS)

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Abstract
This study focuses on the detailed investigation of the electronic and molecular interaction properties of the N-Ethyl-p-toluenesulfonamide (NEPTS) molecule. Density Functional Theory (DFT), a widely used and reliable computational method in quantum chemistry, will be employed to evaluate the structural and electronic characteristics of the molecule. DFT provides critical insights into molecular reactivity, stability, and electronic distribution. The optimized geometry, HOMO and LUMO energy levels, HOMO-LUMO gap, dipole moment, electrostatic potential (MEP) surfaces, and vibrational frequencies of NEPTS will be calculated. These parameters will help identify the molecule's charge distribution and reactive regions. The results will offer valuable information on the chemical reactivity and thermodynamic stability of NEPTS and support its potential evaluation in the field of materials science. In particular, the HOMO-LUMO gap and dipole moment are expected to serve as key indicators of its suitability for electronic and opto electronic applications. By quantitatively analyzing the fundamental electronic and structural properties of NEPTS, this study aims to contribute to the development of new functional materials with potential technological applications.
Keywords: NEPTS, DFT, Opto elektronic

1. Introduction

N-Ethyl-p-toluenesulfonamide (NEPTS) is an organic sulfonamide derivative known for its thermal and chemical stability, making it a candidate of interest in various material science applications. As molecular design becomes increasingly critical in the development of advanced functional materials, understanding the electronic structure and reactivity profile of such compounds is essential [1-4]. Computational chemistry methods, particularly Density Functional Theory (DFT), offer a powerful framework for exploring these properties at the molecular level. In this study, DFT [5, 6] is employed to investigate the optimized geometry, electronic structure, and vibrational characteristics of the NEPTS molecule. Through analysis of key parameters such as the HOMO–LUMO gap, dipole moment, and molecular electrostatic potential, insights into the molecule's reactivity and potential applicability in electronic and optoelectronic technologies are gained. Although NEPTS has previously been examined [3] using theoretical approaches including HF and B3LYP methods, this study provides a more comprehensive analysis by incorporating a broader set of quantum chemical descriptors and visualization tools. The integrated evaluation of electronic, structural, and electrostatic properties presented here aims to deliver a deeper understanding of the molecule's behavior and highlights its potential role in the design of novel functional materials for next-generation technological applications.

2. Optimization and IR Analysis

In this study, the molecular geometry of N-Ethyl-p-toluenesulfonamide (NEPTS) was optimized in the gas phase using Density Functional Theory (DFT) with the B3LYP functional and the 6-311++G(d,p) basis set. The optimization was carried out without symmetry constraints to obtain the most stable conformer. The resulting equilibrium structure was depicted in Fig. 1, and the calculated geometric parameters-comprising bond lengths, bond angles, and dihedral angles-were systematically presented in Table 1. To probe the vibrational behavior of NEPTS, harmonic frequency calculations were also performed at the same level of theory. The vibrational modes were analyzed in detail using the Vibrational Energy Distribution Analysis (VEDA4) [7, 8], which allowed for precise assignments of each normal mode based on potential energy contributions. These assignments, along with the corresponding vibrational frequencies and intensities, were provided in Table 2. Furthermore, the simulated infrared (IR) spectrum, constructed from the theoretical data, was shown in Fig. 2, offering a predictive insight into the characteristic vibrational fingerprints of the molecule.

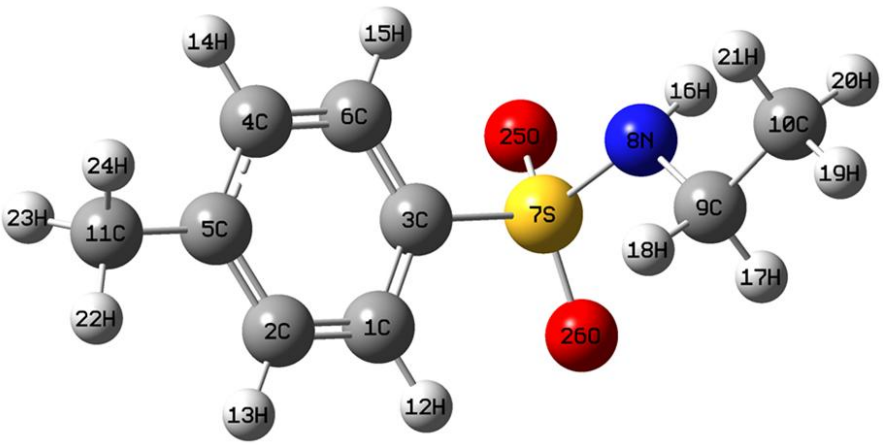

Figure 1. The optimized structure of NEPTS.

Table 1. The optimized structure parameters of NETPS molecule.

Bond Lenghts (A)	Values	Bond Angle (°)	Values	Dihedral Bond Angle (°)	Values	Dihedral Bond Angle (°)	Values
C1-C2	1.390	C9-N8-H16	113.7	C6-C4-C5-C11	-179.0	C3-S7-N8-H16	-145.5
C1-C3	1.390	N8-C9-C10	109.7	H14-C4-C5-C2	179.9	O25-S7-N8-C9	-161.2
C1-H12	1.080	N8-C9-H17	111.4	H14-C4-C5-C11	0.8	O25-S7-N8-H16	-31.3
C2-C5	1.400	N8-C9-H18	107.5	C5-C4-C6-C3	-0.2	O26-S7-N8-C9	-29.5
C2-H13	1.080	C10-C9-H17	110.9	C5-C4-C6-H15	179.5	O26-S7-N8-H16	100.4
C3-C6	1.400	C10-C9-H18	110.0	H14-C4-C6-C3	-180.0	S7-N8-C9-C10	-178.5
C3-S7	1.800	H17-C9-H18	107.4	H14-C4-C6-H15	-0.2	S7-N8-C9-H17	58.4
C4-C5	1.400	C9-C10-H19	110.0	C2-C5-C11-H22	12.2	S7-N8-C9-H18	-59.0
C4-C6	1.390	C9-C10-H20	111.2	C2-C5-C11-H23	-107.8	H16-N8-C9-C10	54.7
C4-H14	1.090	C9-C10-H21	111.1	C2-C5-C11-H24	133.0	H16-N8-C9-H17	-68.4
C5-C11	1.510	H19-C10-H20	107.6	C4-C5-C11-H22	-168.8	H16-N8-C9-H18	174.2
C6-H15	1.080	H19-C10-H21	108.6	C4-C5-C11-H23	71.2	N8-C9-C10-H19	179.1
S7-N8	1.690	H20-C10-H21	108.3	C4-C5-C11-H24	-48.0	N8-C9-C10-H20	-61.9
S7-O25	1.460	C5-C11-H22	111.5	C3-S7-N8-C9	84.6	N8-C9-C10-H21	58.8
S7-O26	1.460	C5-C11-H23	110.8	C3-S7-N8-H16	-145.5	H17-C9-C10-H19	-57.5
N8-C9	1.470	C5-C11-H24	111.3	O25-S7-N8-C9	-161.2	H17-C9-C10-H20	61.5
N8-H16	1.020	H22-C11-H23	107.7	O25-S7-N8-H16	-31.3	H17-C9-C10-H21	-177.8
C9-C10	1.520	H22-C11-H24	108.2	O26-S7-N8-C9	-29.5	H18-C9-C10-H19	61.1
C9-H17	1.100	H23-C11-H24	107.2	O26-S7-N8-H16	100.4	H18-C9-C10-H20	-179.8
C9-H18	1.090	N8-S7-O25	104.6	S7-N8-C9-C10	-178.5	H18-C9-C10-H21	-59.2
C10-H19	1.090	N8-S7-O26	111.0	S7-N8-C9-H17	58.4		
C10-H20	1.090	O25-S7-O26	120.7	S7-N8-C9-H18	-59.0		
C10-H21	1.090	S7-N8-C9	118.2	H16-N8-C9-C10	54.7		
C11-H22	1.090	S7-N8-H16	107.0	H16-N8-C9-H17	-68.4		
C11-H23	1.090	Dihedral Bond Angle (°)	Values	H16-N8-C9-H18	174.2		
C11-H24	1.090	C3-C1-C2-C5	0.2	N8-C9-C10-H19	179.1		
Bond Angle (°)	Values	C3-C1-C2-H13	179.9	N8-C9-C10-H20	-61.9		
C2-C1-C3	119.1	H12-C1-C2-C5	-179.3	N8-C9-C10-H21	58.8		
C2-C1-H12	121.2	H12-C1-C2-H13	0.5	H17-C9-C10-H19	-57.5		
C3-C1-H12	119.7	C2-C1-C3-C6	-0.3	H17-C9-C10-H20	61.5		
C1-C2-C5	121.2	C2-C1-C3-S7	-179.1	H17-C9-C10-H21	-177.8		
C1-C2-H13	119.2	H12-C1-C3-C6	179.2	H18-C9-C10-H19	61.1		
C5-C2-H13	119.6	H12-C1-C3-S7	0.4	H18-C9-C10-H20	-179.8		
C1-C3-C6	121.1	C1-C2-C5-C4	-0.1	H18-C9-C10-H21	-59.2		
C1-C3-S7	119.4	C1-C2-C5-C11	179.0	C6-C4-C5-C11	-179.0		
C6-C3-S7	119.5	H13-C2-C5-C4	-179.8	H14-C4-C5-C2	179.9		
C5-C4-C6	121.2	H13-C2-C5-C11	-0.8	H14-C4-C5-C11	0.8		
C5-C4-H14	119.5	C1-C3-C6-C4	0.3	C5-C4-C6-C3	-0.2		
C6-C4-H14	119.3	C1-C3-C6-H15	-179.4	C5-C4-C6-H15	179.5		
C2-C5-C4	118.4	S7-C3-C6-C4	179.1	H14-C4-C6-C3	-180.0		
C2-C5-C11	121.2	S7-C3-C6-H15	-0.7	H14-C4-C6-H15	-0.2		
C4-C5-C11	120.4	C1-C3-S7-N8	-113.0	C2-C5-C11-H22	12.2		
C3-C6-C4	119.1	C1-C3-S7-O25	136.4	C2-C5-C11-H23	-107.8		
C3-C6-H15	120.2	C1-C3-S7-O26	3.9	C2-C5-C11-H24	133.0		
C4-C6-H15	120.8	C6-C3-S7-N8	68.2	C4-C5-C11-H22	-168.8		
C3-S7-N8	102.4	C6-C3-S7-O25	-42.4	C4-C5-C11-H23	71.2		
C3-S7-O25	109.5	C6-C3-S7-O26	-174.9	C4-C5-C11-H24	-48.0		
C3-S7-O26	107.1	C6-C4-C5-C2	0.1	C3-S7-N8-C9	84.6		

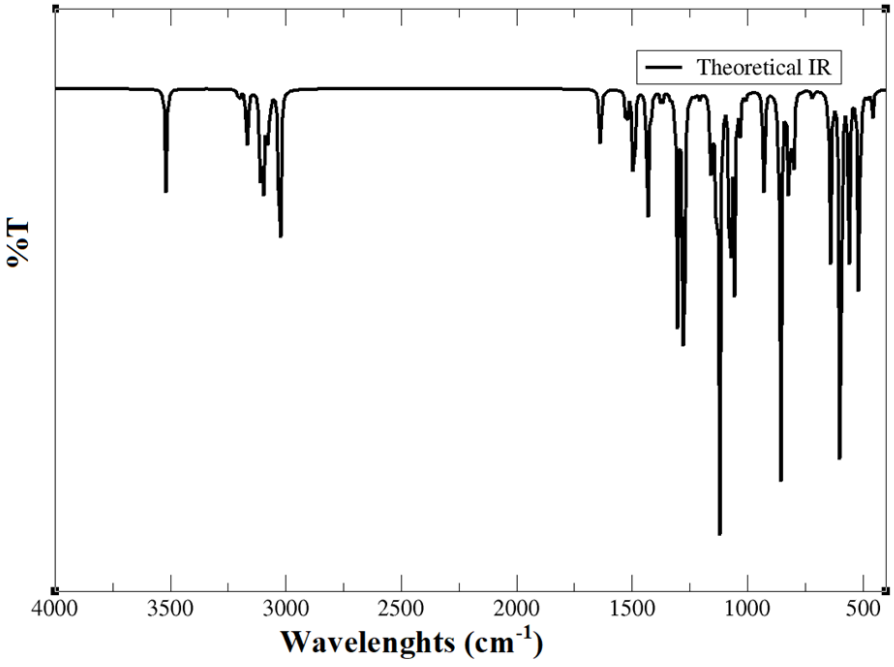

Figure 2. The theoretical IR spectra of NEPTS.

Table 2. The theoretical assignments of NETPS molecule.

Modes	Intensity	Unscaled	Scaled	Assignments
υ1	29.91	3519.63	3384	ϑ NH(100)
υ2	2.69	3204.37	3081	ϑ CH(99)
υ3	1.02	3200.03	3077	ϑ CH(101)
υ4	10.70	3169.83	3047	ϑ CH(100)
υ5	10.47	3165.08	3043	ϑ CH(99)
υ6	26.75	3109.07	2989	ϑ CH(100)
υ7	14.34	3108.13	2988	ϑ CH(94)
υ8	31.01	3094.21	2975	ϑ CH(91)
υ9	13.26	3078.65	2960	ϑ CH(99)
υ10	6.55	3068.34	2950	ϑ CH(80)
υ11	21.70	3028.43	2912	ϑ CH(95)
υ12	20.36	3026.92	2910	ϑ CH(92)
υ13	26.22	3026.37	2910	ϑ CH(84)
υ14	21.74	1637.51	1574	ϑ CC(56)
υ15	0.69	1613.74	1551	ϑ CC(49)+β CCC(24)
υ16	4.75	1524.93	1466	β HCC(21) + β HCH(21)
υ17	10.26	1523.47	1465	β HCH(49) + τ HCNS(12)
υ18	3.53	1499.40	1442	β HCH(74) + τ HCCN(13)
υ19	15.13	1494.64	1437	β HCH(71) + τ HCCC(10)
υ20	10.45	1492.49	1435	β HCH(72) + τ HCCN(15)
υ21	8.11	1488.20	1431	β HCH(77)
υ22	36.29	1433.58	1378	β HNC(37) + τ HCNS(36)
υ23	8.23	1428.56	1373	ϑ CC(24) + β HCC(24)
υ24	2.02	1415.38	1361	β HCH(88)
υ25	3.69	1415.05	1360	β HCH(78)
υ26	6.23	1372.05	1319	β HNC(24) + β HCC(33) + τ HCNS(17)
υ27	1.48	1334.89	1283	ϑ CC(44) + β HCC(13)
υ28	0.41	1331.39	1280	ϑ CC(15) + β HCC(59)
υ29	66.78	1304.39	1254	ϑ SO(21) + β HCC(31) + τ HCNS(10)
υ30	126.03	1276.54	1227	ϑ SO(69)
υ31	1.47	1228.84	1181	ϑ CC(56)
υ32	2.37	1206.50	1160	ϑ CC(20) + β HCC(71)
υ33	30.60	1157.50	1113	τ HCNS(27) + τ HCCN(26)
υ34	12.78	1138.60	1095	ϑ NC(12) + β HCC(10) + τ HCCN(11)
υ35	17.42	1136.77	1093	ϑ NC(12) + τ HCCN(15)
υ36	138.42	1121.26	1078	ϑ CC(27) + ϑ SO(30) + ϑ SC(13)
υ37	79.76	1075.67	1034	ϑ CC(12) + ϑ SO(54)
υ38	6.43	1061.36	1020	β HCH(12) + τ HCCC(70)
υ39	53.40	1056.27	1015	ϑ CC(52) + ϑ NC(33)
υ40	13.05	1033.53	994	β CCC(60)
υ41	2.11	1007.97	969	β CCC(10) + β HCH(17) + τ HCCC(51)
υ42	0.35	992.94	955	τ HCCS(82)
υ43	0.15	969.85	932	τ HCCS(55) + τ CCCC(19)
υ44	34.56	929.71	894	ϑ CC(30) + ϑ NC(24) + ϑ SN(11) + τ HCCN(21)
υ45	117.81	857.22	824	ϑ SN(25) + τ HNCC(13) + τ HCCN(16)
υ46	8.72	852.31	819	τ HCCS(88)
υ47	26.35	824.47	793	τ HCCS(80)
υ48	10.97	814.70	783	ϑ CC(11) + τ HCNS(19) + τ HCCN(10)
υ49	31.46	802.80	772	ϑ CC(11) + ϑ SN(10) + τ HCNS(15)
υ50	2.76	718.11	690	τ CCCC(51) + ω CCCC(13)
υ51	0.23	647.80	623	β CCC(80)
υ52	52.90	641.13	616	ϑ CC(15) + ϑ SC(23) + β CCC(11) + ω ONOS(15)
υ53	134.50	597.90	575	ϑ SN(12) + β OSO(17) + τ HNCC(31)
υ54	48.24	559.80	538	ω ONOS(23)
υ55	75.59	517.73	498	β CCC(10) + τ HNCC(19) + ω ONOS(26)
υ56	1.82	479.62	461	β OSO(32) + τ CCCC(14) + ω CCCC(16)
υ57	9.62	457.90	440	β OSN(15) + β SCC(14) + ω ONCS(35)
υ58	0.11	415.57	400	τ CCCC(82)
υ59	5.84	377.79	363	β CCC(30) + β OSN(27)
υ60	3.57	346.43	333	β OSO(18) + β NSC(21) + ω CCCC(12)
υ61	0.92	322.19	310	ϑ SN(19) + β CCC(11) + β CCN(24)
υ62	0.04	312.16	300	β CCC(25) + β CCN(14) + β OSN(16) + ω ONCS(10)
υ63	3.08	279.64	269	ϑ SC(41) + β CCC(14)
υ64	1.76	254.24	244	τ HCCN(44)
υ65	0.65	209.99	202	β NSC(18) + τ CCCC(12) + ω CCCC(11) + ω SCCC(10)
υ66	0.83	166.51	160	β CNS(27) + β OSN(12) + β SCC(29)
υ67	1.36	150.32	145	β CNS(30) + β SCC(29) + ω ONCS(20)
υ68	0.41	103.47	99	τ CCCC(24) + τ CNSC(26) + ω SCCC(18)
υ69	1.41	75.56	73	τ HCNS(14) + τ CCNS(36) + τ CNSC(29)
υ70	0.36	40.09	39	β NSC(13) + τ HCCC(24)+τ CCNS(22)+τ CNSC(17)+ωSCCC(12)
υ71	0.68	34.38	33	τ HCCC(38) + τ CCNS(12)
υ72	0.27	25.11	24	τ NSCC(89)

ϑ - streching, β - bending, τ - torsion, ω - out plane bending.

3. Frontier Orbital Analysis

The electronic properties of NEPTS were further explored through analysis of its frontier molecular orbitals. The spatial distributions of the HOMO and LUMO orbitals, which reveal the electron-rich and electron-deficient regions of the molecule, were illustrated in Fig. 3. The corresponding energy values, along with key reactivity descriptors such as the HOMO-LUMO gap, chemical hardness, and electrophilicity, were listed in Table 3. These findings provide essential insight into the molecule's chemical reactivity and potential for charge transfer processes [9-15].

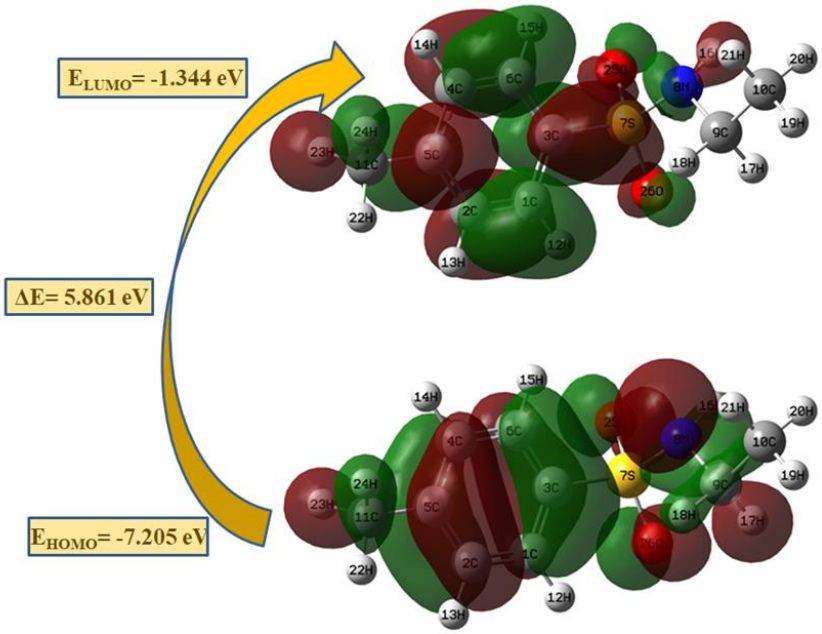

Figure 3. The frontier orbitals of NEPTS.

Table 3. Some global reactivity descriptors the computed for NETPS molecule.

Parameters (eV)	Values
E_{LUMO}	-1.344
E_{HOMO}	-7.205
Energy bandgap ($\lvert E_{HOMO}-E_{LUMO} \rvert$)	5.861
Ionization potential ($I = -E_{HOMO}$)	7.205
Electron affinity ($A = -E_{LUMO}$)	1.344
Chemical hardness ($\eta = (I-A)/2$)	2.931
Chemical softness ($\zeta = 1/2\eta$)	0.171
Electronegativity ($\chi = (I+A)/2$)	4.275
Chemical potential ($\mu = -(I+A)/2$)	-4.275
Electrophilicity index $\omega = \mu^2/2\eta$	3.117
Maximum charge transfer index ($\Delta N_{max.} = -\mu/\eta$)	1.459

4. MEP Analysis

The Molecular Electrostatic Potential (MEP) map of NEPTS was generated to visualize the charge distribution across the molecular surface and identify potential sites for electrophilic or nucleophilic interactions. As shown in Fig. 4, the MEP surface and its corresponding color scale reveal regions of electron density, highlighting chemically reactive zones. This analysis supports a deeper understanding of the molecule's polarity and intermolecular interaction tendencies [9-15].

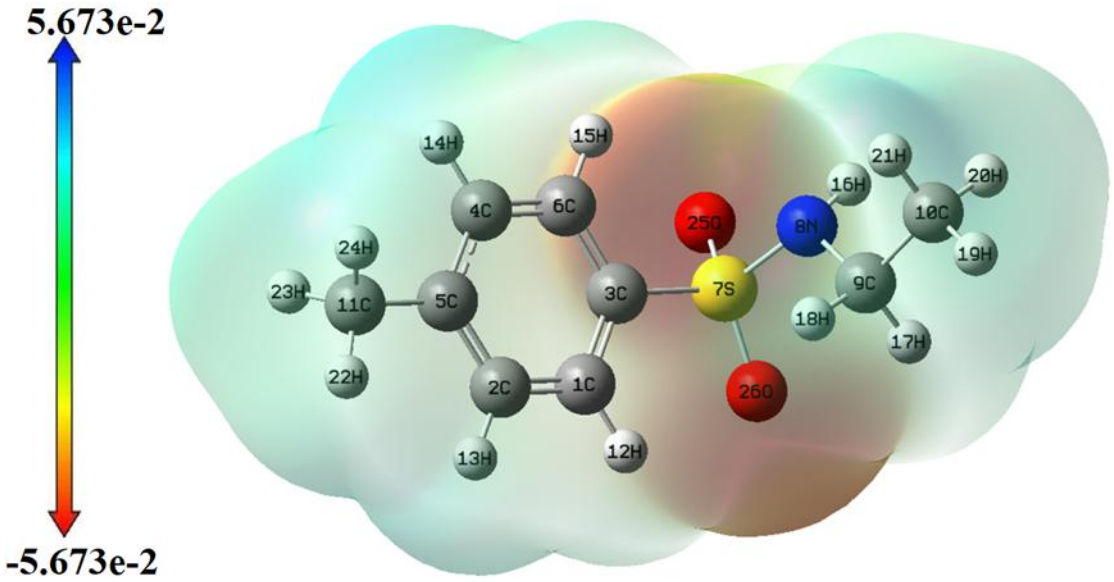

Figure 4. The MEP surfaces of NEPTS

5. Conclusion

Based on the comprehensive computational analysis of N-Ethyl-p-toluenesulfonamide (NEPTS), the following conclusions can be drawn:

- The molecular geometry of NEPTS was successfully optimized at the B3LYP/6-311++G(d,p) level, and the calculated structural parameters provide a reliable foundation for understanding its conformational stability.
- Vibrational frequency analysis, supported by VEDA assignments, revealed characteristic IR-active modes that can serve as spectral fingerprints for experimental comparison.
- Frontier molecular orbital analysis indicated a moderate HOMO–LUMO gap, suggesting a balance between electronic stability and reactivity, with potential implications for electronic and optoelectronic applications.
- The calculated chemical descriptors, such as hardness, softness, and electrophilicity index, further support the molecule's potential role in charge transfer processes and reactive environments.
- The MEP map highlighted distinct electron-rich and electron-deficient regions, offering insight into possible interaction sites for electrophilic and nucleophilic attack.

Overall, the theoretical findings contribute to a deeper understanding of the electronic,

structural, and reactive characteristics of NEPTS, reinforcing its potential as a candidate for advanced material applications.

Acknowledgement

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DOCKING ANALYSIS OF N-ETHYL-P-TOLUENESULFONAMIDE (NEPTS)

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Abstract
In this study, the potential biological activities of the NEPTS (N-ethyl-p-toluenesulfonamide) molecule were evaluated through molecular docking analyses with selected target proteins. Using the molecular docking method, interactions between the ligand and target proteins were modeled, and potential binding sites and affinities were predicted. Within this scope, NEPTS was docked with biological target proteins associated with anticancer, antiepileptic, and antihypertensive effects. The binding affinities, interaction energies, and critical amino acid residues involved in NEPTS–protein complexes were identified. The data obtained revealed the molecule's possible effects within biological systems and supported its pharmacological potential. Accordingly, a scientific basis for considering NEPTS as a drug candidate was established. As a result, the interactions of the NEPTS molecule with potential biological targets were comprehensively elucidated using in-silico approaches. The findings were considered to offer valuable insights into modern drug design and development processes.
Keywords: NEPTS, Molecular Docking, Drug Candidate

1. Introduction

The search for novel bioactive compounds with therapeutic potential remains a critical focus in modern drug discovery. Among these, sulfonamide derivatives have garnered significant attention due to their wide spectrum of pharmacological activities, including antimicrobial, anticancer, antiepileptic, and antihypertensive effects. N-ethyl-p-toluenesulfonamide (NEPTS), a member of this chemical class, possesses a structural framework conducive to various biological interactions. However, its pharmacological profile remains insufficiently explored [1-4]. In silico approaches, particularly molecular docking analyses, offer a valuable platform for predicting ligand–protein interactions and evaluating the drug-likeness of candidate molecules. In this study, the binding behavior of NEPTS with selected target proteins associated with cancer, epilepsy, and hypertension was systematically investigated. The aim was to elucidate its potential as a multifunctional therapeutic agent through computational modeling of binding affinities and interaction mechanisms. The results provide a rational foundation for further preclinical evaluation of NEPTS and contribute to the expanding knowledge in rational drug design .

2. Molecular Docking Analysis

Drug discovery is a long and multi-phase process that requires substantial time, cost, and resources [5-7], as illustrated in Fig. 1.

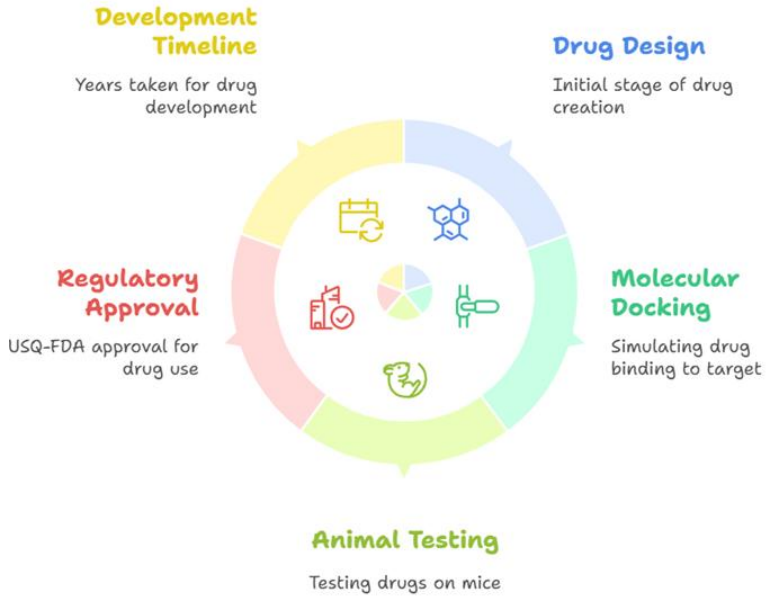

Figure 1. Drug development process.

To streamline early-stage screening and prioritize potential drug candidates, molecular docking has become an indispensable computational tool [8-10]. It enables the prediction of binding affinities and interaction modes between small molecules and their biological targets, thus accelerating the drug development pipeline. In the present study, the potential protein target of N-ethyl-p-toluenesulfonamide (NEPTS) was predicted using the SwissTargetPrediction platform, identifying carbonic anhydrase (PDB ID: 12CA) as a likely target (Fig. 2).

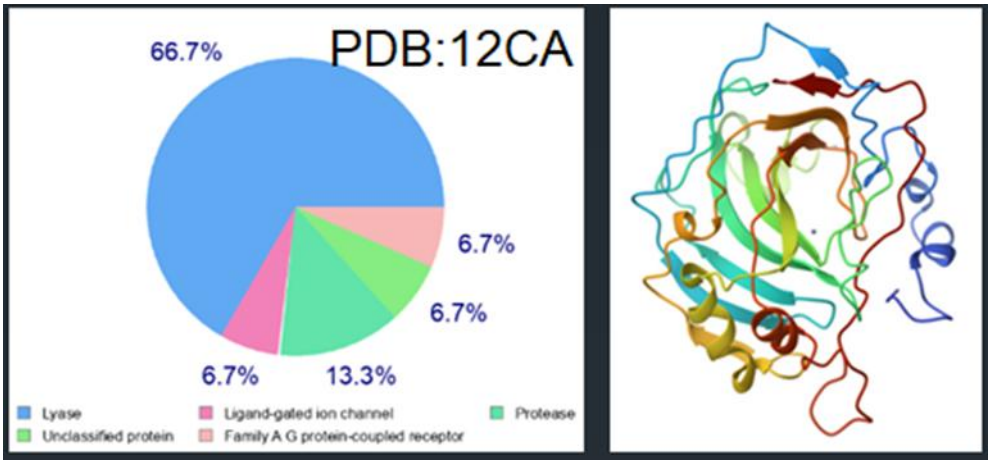

Figure 2. SwissTarget scores of NEPTS.

Following this, docking simulations were conducted to explore the binding pose and interaction dynamics of NEPTS within the active site of the selected protein. The resulting NEPTS–protein complex was visualized through three-dimensional and two-dimensional interaction diagrams, which highlighted key binding interactions (Fig. 3). These docking-based insights provide a valuable foundation for understanding the pharmacological relevance of NEPTS and for guiding its further development as a therapeutic candidate. All docking calculations were performed using AutoDock Vina [11].

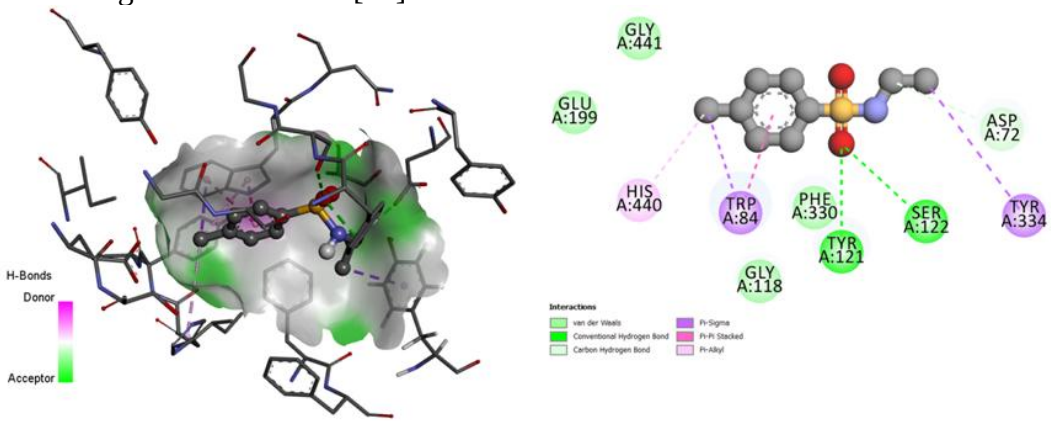

Figure 3. 3D and 2D docking scores of NEPTS.

3. Drug-Likeness and ADME Analysis

Evaluating the drug-likeness and pharmacokinetic behavior of candidate molecules is essential in early-stage drug discovery to predict their oral bioavailability, permeability, and overall suitability as therapeutic agents. In this context, the drug-likeness and ADME (Absorption, Distribution, Metabolism, and Excretion) properties of NEPTS were investigated using the SwissADME web tool [12]. The results indicated that NEPTS complies with Lipinski's Rule of Five [13], suggesting favorable physicochemical properties for oral bioavailability. Furthermore, the bioavailability radar plot (Fig. 4) confirmed that the molecule falls within the optimal range for key parameters such as size, polarity, solubility, and lipophilicity. The BOILED-Egg model (Fig. 5) further demonstrated that NEPTS is capable of crossing the blood–brain barrier, which is a valuable feature for molecules targeting the central nervous system. These findings support the pharmacokinetic viability of NEPTS and highlight its potential for further drug development studies.

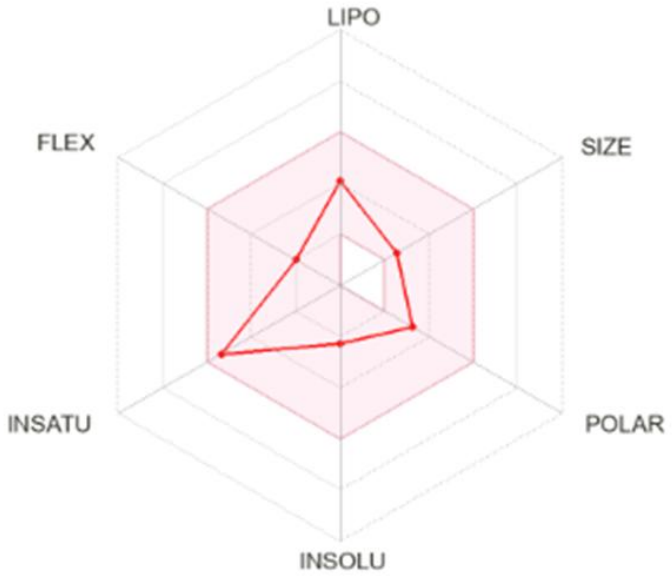

Figure 4. The BOILED-Egg model of NEPTS.

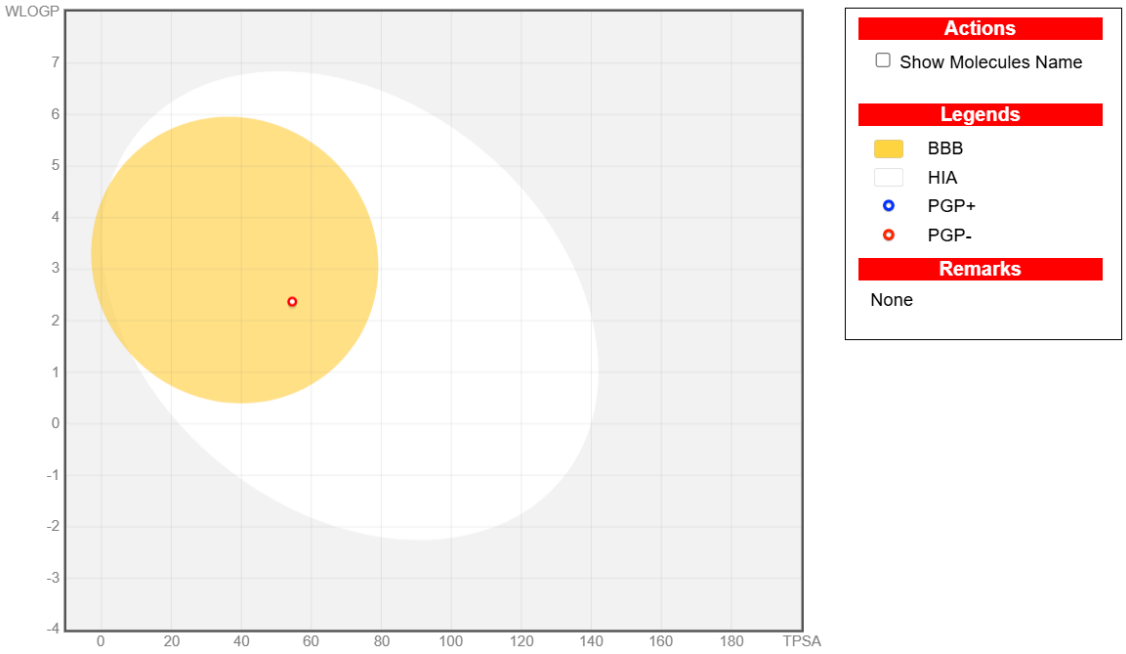

Figure 5. The bioavailability radar plot of NEPTS.

4. Conclusion

- The molecular docking studies demonstrated that NEPTS exhibits favorable binding interactions with carbonic anhydrase (PDB ID: 12CA), suggesting its potential as a biologically active compound.
- Docking simulations revealed stable ligand–protein complexes with meaningful binding affinities and key amino acid interactions, providing a molecular basis for further pharmacological evaluation.

- Drug-likeness analysis confirmed that NEPTS complies with Lipinski's Rule of Five, indicating suitable properties for oral administration and drug development.
- The bioavailability radar analysis showed that NEPTS falls within optimal physicochemical ranges, supporting its potential for effective absorption and systemic distribution.
- The BOILED-Egg model predicted the ability of NEPTS to cross the blood–brain barrier, highlighting its promise for central nervous system–related therapeutic applications.

Overall, the combined in silico results support the consideration of NEPTS as a promising lead compound in drug design, warranting further experimental validation through in vitro and in vivo studies.

Acknowledgement

The authors would like to thank Science and Technology Practice & Research Centre of Bozok University for financial support (Project No: FED-2025-1562).

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YENİ BİR PROTEİN KAYNAĞI OLARAK SU MERCİMEĞİNİN (*Lemna minor*) KULLANIM OLANAKLARININ ARAŞTIRILMASI

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Özet
Dünya nüfusunun hızla artması ve iklim krizi, gıda ve yem tedarikini tehdit eden ciddi bir sorun haline gelmiş, protein ve vitamin açısından yetersiz beslenme kalıpları, basit şekerlerin aşırı tüketimi nedeniyle yetersiz beslenmenin gelişmesi ve besin maddelerinin damgalanması gibi sorunlar ortaya çıkmıştır. Bununla birlikte özellikle gelişmiş ülkelerde yaşanan bu sorunlardan dolayı hayvansal protein kaynaklarında azalma meydana gelmeye başlamıştır. Bu nedenle son zamanlarda beslenmede hayvansal proteine alternatif protein kaynağı olarak bitki bazlı proteinler tercih edilmeye başlanmıştır. Bu anlamda, kara bitkilerine bir alternatif olarak yüzen bitkiler de dahil olmak üzere su bitkilerinin protein kaynağı olarak kullanılmaları son yıllarda araştırılmaktadır. Sucul bitkiler grubunda yer alan su mercimekleri, Araceae familyasının çiçekli bitkileridir. Su mercimekleri tatlı sularda çoğunlukla su birikintilerinde, bataklıklarda, göllerde ve sakin nehirlerde yaşayan, su üzerinde yüzen veya kısmen suya batık halde bulunan, çok yıllık otsu bitkilerdir. Geleneksel olarak, su kütlelerindeki mineralleri, tuzları, azotlu maddeleri ve ağır metalleri emme yetenekleri nedeniyle su kütlesi kirliliği için iyileştirme ajanları olarak kullanılmaktadır. Son yıllarda su mercimeklerinin soya fasulyesinden sonra protein miktarı bakımından zengin bir bir protein kaynağı olduğu bilinmektedir. Bununla birlikte Sumercimekleri doymuş yağ asidi, tekli doymamış ve çoklu doymamış yağ asidi miktarları bakımından da insan beslenmesinde besin değerini artırabilmektedir. Bu çalışmada özellikle *Lemna minör* türü olmak üzere su mercimeklerinin besinsel bileşimleri ve güncel kullanımlarının hakkında bilgi sunulacaktır.
Anahtar kelimeler: Su mercimeği, *Lemna minör*, Protein içeriği, Besinsel bileşimi

INVESTIGATION OF THE UTILIZATION POSSIBILITIES OF DUCKWEED (*Lemna minor*) AS A NEW PROTEIN SOURCE

Abstract
The rapid increase in the world population and the climate crisis have become serious problems threatening food and feed supply, and problems such as inadequate dietary patterns in terms of protein and vitamins, the development of malnutrition due to excessive consumption of simple sugars and the stigmatization of nutrients have emerged. However, due to these problems, especially in developed countries, animal protein sources have begun to decrease. For this reason, plant-based proteins have recently begun to be preferred as an alternative protein source to animal protein in nutrition. In this sense, the use of aquatic plants, including floating plants, as a protein source has been investigated in recent years as an alternative to land plants. Duckweed, which is in the group of aquatic plants, is a flowering plant of the Araceae family. Duckweed is a perennial herbaceous plant that lives mostly in puddles, marshes, lakes and calm rivers in freshwater, floating on the water or partially submerged in the water. Traditionally, it has been used as a remediation agent for water body pollution due to its ability to absorb minerals, salts, nitrogenous substances and heavy metals in water bodies. In recent years, it has been known that duckweed are a rich source of protein after soybeans. In addition, water lentils can increase the nutritional value in human nutrition in terms of saturated fatty acid, monounsaturated and polyunsaturated fatty acid amounts. In this study, information will be presented about the nutritional composition and current uses of water lentils, especially the *Lemna minor* species.
Keywords: Duckweed, *Lemna minör*, Protein content, Nutritional composition

Giriş

Dünya nüfusunun hızla artması ve iklim krizi, gıda ve yem tedarikini tehdit eden ciddi bir sorun haline gelmiş, protein ve vitamin açısından yetersiz beslenme kalıpları, basit şekerlerin aşırı tüketimi nedeniyle yetersiz beslenmenin gelişmesi ve besin maddelerinin damgalanması gibi sorunlar ortaya çıkmıştır. Bununla birlikte özellikle gelişmiş ülkelerde yaşanan bu sorunlardan dolayı hayvansal protein kaynaklarında azalma meydana gelmeye başlamıştır. Bu nedenle son zamanlarda beslenmede hayvansal proteine alternatif protein kaynağı olarak bitki bazlı proteinler tercih edilmeye başlanmıştır (Prada ve ark., 2024). Bu anlamda, kara bitkilerine bir alternatif olarak yüzen bitkiler de dahil olmak üzere su bitkilerinin protein kaynağı olarak kullanılmaları son yıllarda araştırılmaktadır. Su mercimeği, gelecekteki gıda ürünleri için bitki bazlı bir bileşen ve hayvansal eti değiştirme potansiyeli olan, daha sağlıklı ve daha uygun fiyatlı bir protein kaynağı olan sürdürülebilir bir alternatif protein kaynağı olarak düşünülebilir (Appenroth vd., 2018). Su mercimeği, göller ve göletler gibi yavaş akan su kütlelerinde yaygın olarak bulunabilen, küçük ve serbestçe yüzen bitkiler olarak bilinen suda yaşayan yeşil bir bitkidir. Dünya çapında en küçük çiçekli bitkidir ve suda asılı tek bir kökü olan üçten az yapraktan oluşmaktadır. Bununla birlikte, su mercimeğinin yaprakları vejetatif yöntemle çoğaltılarak günlük verimde %50 artış sağlanabilir. Su mercimeğinin besin içeriği ve metabolit bileşimi, özellikle hayvan yemi endüstrisinde, su ürünleri yetiştiriciliğinde, sağlık takviyesinde, biyogübrede, biyoyakıtta ve insanlar için ortaya çıkan gıda ürünlerinde yoğun ilgi görmüştür. Su mercimeğinin tahıldan daha yüksek olan %20 ila %30 oranında protein içerdiği bildirilmiştir(de Beukelaar ve ark., 2019; Naseem ve ark., 2020; Miltko ve ark., 2024). Bu çalışmada, özellikle Lemna minör türü olmak üzere su mercimeklerinin besinsel bileşimleri ve güncel kullanımlarının hakkında bilgi sunulacaktır.

Su mercimeğinin yapısı

Su mercimeği ailesi Lemnaceae, Alismatales monokotil takımına aittir ve beş cinsi temsil eden 36 tanınmış türden oluşur: Spirodela (Sp.), Landoltia (La.), Lemna (Le.), Wolffiella (We.) ve Wolffia (Wo). Su mercimeği genel adı, ördekler gibi su kuşlarıyla birlikte küresel dağılımlarından ve muazzam büyümelerinden kaynaklanmaktadır. Kutup bölgeleri hariç, göletler ve göller gibi durgun ve yavaş akan sularda minik bitkiler olarak dünya çapında tüm coğrafi bölgelerde büyüyebilmektedir Morfolojik olarak, su mercimeği türleri 5 mm uzunluğunda düz oval şekillidir ve sapları veya gerçek yaprakları yoktur. Klonal büyüme (ana/kız yapraklar) yoluyla hızlı büyür ve uygun koşullar altında biyokütlesini 2-3 günde ikiye katlayabilir. Su mercimeği büyümesi ve biyokütle birikimi, su durumu (besin konsantrasyonu, sıcaklık ve pH), ışık (maruz kalma süresi ve yoğunluk) ve rüzgar hızı gibi çevresel faktörlerden etkilenmektedir. Ek olarak, gübre açısından zengin ortam ve artan ışık yoğunluğu/fotoperiyodun *Lemna minor* (*L. minor*) ve *Lemna aequinoctialis* (*L. aequinoctialis*) gibi türlerin büyümesini ve nişasta birikimini artırdığı gösterilmektedir (Xu ve ark., 2021). Lemnaceae familyasına ait su mercimeği türlerinden biri olan Lemna minor, eliptik form, ortalama 1,7 mm çapında düzenli tür büyüklüğü, 2-4 yaprak kolonisi göstermektedir (Şekil 1) L. minor besinleri almak için hem kökleri hem de yapraklarını kullanırken, köksüz bir bitki olan Wolffia globosa, büyüme ortamından besinleri almak için yaprak yüzeyini kullanmaktadır. (Acosta ve ark., 2021; Yahaya ve ark., 2022).

Şekil 1. Su mercimeği (vikipedi)

Su mercimeğinin besinsel bileşimi

Su mercimeğindeki protein içeriği çoğu tahıl tanesindekine benzer ve hatta daha yüksektir ve su mercimeği ayrıca tahıl tanelerine kıyasla daha yüksek lif, lipit ve mineral içeriğine sahiptir. Su mercimeği besin içeriği açısından karakterize edilmiştir ve tür ve büyüme koşulları kimyasal içerik ve temel besin maddeleri üzerinde önemli bir etkiye sahiptir. Örneğin, protein içeriği %16,0 (*Lemna sp.*) ile %41,7 (*Landoltia. gibba*) arasında, nişasta %17,6 (*L. gibba*) ile %35,0 (*Lemna sp.*), lipit % 3,4 (Landoltia. minor) ile %9,0 (*Lemna sp.*), ham lif % 8,8 (Spirodela. polyrhiza) ile %29,7 (*L. minor*) arasında ve kül % 3,5 (*L. gibba*) ile %26,0 (*Lemna sp.*) arasında değişmektedir (Xu ve ark.,2021). Su mercimeği ayrıca %4 ila %7 oranında yağ, %4 ila %10 oranında nişasta, karotenoidler ve flavonoidler gibi polifenoller ve antosiyaninler içerir (Appenroth ve ark., 2018). Su mercimeği yapraklarındaki antioksidan enzimlerin aktivitelerinde bakırın neden olduğu değişiklikler incelendi. Bu etkilerinin yanı sıra, su mercimeği yaygın olarak analjezik ve antipiretik ilaçların üretimi için bir ham madde olarak kullanılmaktadır (Gülçin ve ark., 2010).

Yüksek kaliteli protein içeriği, optimum koşullar altında yetiştirildiğinde kuru maddede %20 ila %35'e ulaşır ve tahıllarda bulunan proteinden daha yüksektir (Appenroth ve ark., 2018; Baek ve ark., 2021). Bu, yaygın su mercimeği biyokütlesinin hayvan veya insan gıdası için bir bileşen olarak kabul edilebileceği ve yüksek besin değerine sahip gıda üretmenin sürdürülebilir yöntemlerinin geliştirilmesi yoluyla gıda güvenliğinin iyileştirilmesine katkıda bulunabileceği düşünülmektedir. Su mercimeğindeki ana protein, iyi bir temel amino asit kaynağı olan ribuloz-1, 5-bisfosfat karboksilazdır (RuBisCO). Ayrıca, RuBisCO proteini besin değeri, in vitro sindirilebilirliği ve alerjen olmaması nedeniyle işlevsel bir gıda olarak iyi bir adaydır. (Chakrabarti ve ark., 2018). Ek olarak, RuBisCO proteini iyi jelleştirme ve emülsifikasyon özelliklerine, yüksek köpürme kapasitesine ve yüksek çözünürlüğe sahiptir. Ayrıca, Wolffia zengin bir protein kaynağı olarak tanınmıştır ve geleneksel olarak Güneydoğu Asya'da doğal bir gıda kaynağı olarak kullanılır. Wolffia cinsinde birçok alt tür vardır ve en yaygın olanı Wolffia globosa olarak bilinir. *W. globosa*, Tayland'da su unu veya Khai Nam olarak bilinir. Çiğ Wolffia, salatalar, omletler veya sebze körileri gibi belirli yemekleri yapmak için kullanılmaktadır (Di Stefano ve ark. 2018).

Yağ önemli bir besindir ve yaşam aktivitelerini desteklemek için enerji sağlar. Yağ asidi (FA) profili, FA'ların türüne bağlı olarak koroner kalp hastalığına karşı koruma sağlayabileceği veya bu hastalığa neden olabileceği için insan sağlığında kritik bir rol oynar. Su mercimeğindeki yağ içeriği çoklu doymamış yağ asitlerinden, toplam yağ asitlerinin %60 ila %63'ü ve α-linolenik asitin %41 ila %47'sinden oluşur (Chakrabarti ve ark. 2018). Su mercimeğinin nişastası %35,7 amiloz ve %26,5 amilopektin içerir (Lee ve ark. 2016). Yan ve

ark., (2013), otuz su mercimeği türünün FA dağılımını karakterize etti ve toplam yağ asidi (TFA) içeriğinin (kuru ağırlık bazında) % 4,6 (*Wolffiella welwitschii*) ile %14,2 (*Wolffia borealis*) arasında değiştiğini, triasilgliserolün (TAG) ise % 0,02 (*S. polyrhiza*) ile %0,15 (*Wa. lingulata*) arasında değiştiğini gösterdi. Palmitik asit (PA), linoleik asit (LA) ve α-linolenik asit (ALA), su mercimeğindeki TFA'nın %80'inden fazlasını oluşturuyordu. Test edilen otuz su mercimeği türü arasında, yedi Lemna türü ve bir Wolffiella türü linolenik asit (GLA) ve ALA içeriyordu. Tang ve ark., (2015) tarafından yürütülen başka bir çalışma, TFA içeriğinin %1,05 (L. punctate ve *S. polyrhiza*) ile %1,62 (*Wo. globosa*) arasında değiştiğini (kuru ağırlık bazında) gösterdi; burada, PA, LA ve linolenik asit de TFA'nın %80'inden fazlasını oluşturuyordu. Ek olarak, *L. punctata, L. aequinotialis, S. polyrhiza* ve *Wo. globosa* türleri arasında TAG açısından önemli bir fark yoktu.

Su mercimeği, nişasta, selüloz, eser hemiselüloz, pektin ve diğerleri gibi çok yönlü karbonhidratlar içerir. Belirli karbonhidrat içerikleri türe ve büyüme koşullarına bağlıdır. Örneğin, su mercimeği nişastası, türe ve çeşitlere, konumlara, besin bulunabilirliğine ve diğer büyüme koşullarına bağlı olarak kuru bazda %3 (L. aequinoctialis) ile %75 (L. punctata) arasında büyük ölçüde değişmektedir (Yin ve ark., 2015; Xu ve ark., 2024).

Sonuç

Su mercimeği, su ürünleri üretimi ve hızlı büyüme gibi birçok avantajlı özelliği nedeniyle gelecekte küresel olarak gıda kıtlığı stresini hafifletmek için potansiyel bir gıda kaynağıdır. Ek olarak, belirli su mercimeği türleri yüksek protein ve diyet lifi içeriği, yeterli temel amino asitler, sağlığı geliştiren mikro besinler ve antioksidanlar gibi birçok kritik besin içerir. Proteinler, karbonhidratlar, yağlar ve fitokimyasallar gibi su mercimeği bileşenleri bazı büyük işlevsel ve besinsel faydalar göstermiş olsa da, kimyalarını, yapılarını, işlevlerini ve sağlık açısından yararlı etkilerini daha iyi anlamak ve açıklamak için daha fazla araştırma gerekmektedir.

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YABANİ SARIMSAK OLARAK BİLİNEN KÖRMEN (*Allium Scorodoprasum* L.) OTU ÖZELLİKLERİ VE KULLANIMI

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Özet

Türkiye, bitki popülasyonu çeşitliliği açısından dünyada önemli bir konuma sahiptir. Ülkemizde kültür bitkisi ve doğal olarak yetişen bitki türü bulunmaktadır ve bu bitki türlerinin birçoğunu tıbbi ve aromatik bitkilerden oluşmaktadır. Tıbbi ve aromatik bitkilerden birisi olan ve körmen, kaya sarımsağı, delice pırasa, vahşi sarımsak, sirmo, çatlanguş, köpek soğanı ve çoban sarımsağı gibi farklı geleneksel isimlerle bilinen *Allium scorodoprasum subsp. rotundum*, Alliaceae ailesinin bir üyesidir. Sarımsak, pırasa, frenk soğanı ve arpacık soğanı olmak üzere Allium cinsine ait yaklaşık 800 tür bulunmaktadır. A. rotundum dünyada yabani pırasa (WL) olarak bilinir. Türkiye`de dahil olmak üzere dünyanın çeşitli ülkelerinde doğal olarak yetişir. Doğu Anadolu ve Kuzey Anadolu bölgelerinde yetiştirilmektedir. Bunlar, kendilerine karakteristik lezzetlerini veren bazı uçucu kükürt bileşiklerinin yanı sıra diyet lifi, şekerler, flavonoidler ve uçucu yağlar içerir Allium türlerinin antimikrobiyal, antitümör antifungal, antibakteriyel, kemopreventif, antihipertansif antikanser ve antikoagülan aktivitesi gibi özelliklere sahip olduğu yapılan çalışmalarda bildirilmiştir. Körmen otunun yaprakları, çiçekleri, sap ve soğan kısımları gıda veya geleneksel tıpta tedavi amaçlı kullanılmaktadır. Bu çalışma, Allium cinsine ait olan ve birçok farklı isimlerle bilinen *A. scorodoprasum* L. subsp. *rotundum* bitkisinin antioksidan ve antimikrobiyal aktivitelere ek olarak, antidiyabetik, sitotoksik ve özellikle antiinflamatuar aktiviteler dahil olmak üzere biyoaktif özellikleri, yanısıra kullanım alanları anlatılacaktır.

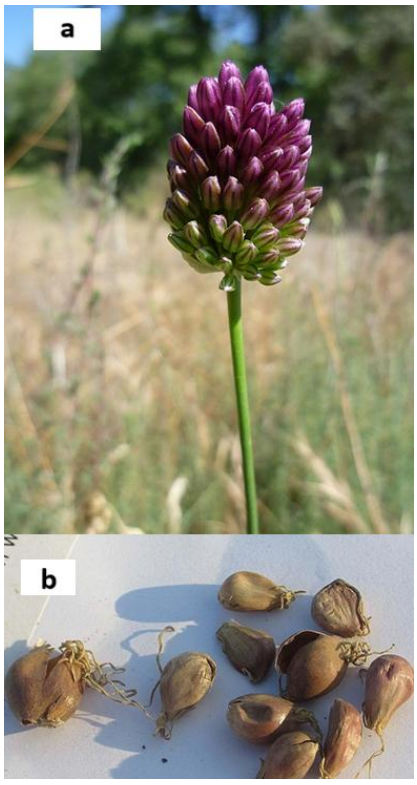
Anahtar kelimeler: Körmen otu, *Allium scorodoprasum subsp. rotundum*, Biyoaktivite özellikleri

PROPERTIES AND USES OF THE HERB CURMEN (*Allium scorodoprassum* L.), KNOWN AS WILD GARLIC

Abstract
Türkiye has an important position in the world in terms of plant population diversity. There are cultivated and naturally growing plant species in our country and many of these plant species are medicinal and aromatic plants. One of the medicinal and aromatic plants, *Allium scorodoprasum subsp. rotundum*, known by different traditional names such as blindmen, rock garlic, crazy leek, wild garlic, sirmo, crackling, dog onion and shepherd garlic, is a member of the Alliaceae family. There are approximately 800 species belonging to the genus Allium, including garlic, leeks, chives and shallots. *A. rotundum* is known as wild leek (WL) in the world. It grows naturally in various countries of the world, including Türkiye. It is cultivated in Eastern Anatolia and Northern Anatolia regions. They contain dietary fiber, sugars, flavonoids and essential oils as well as some volatile sulfur compounds that give them their characteristic flavor. Studies have reported that Allium species have properties such as antimicrobial, antitumor antifungal, antibacterial, chemopreventive, antihypertensive anticancer and anticoagulant activity. The leaves, flowers, stem and bulb parts of Körmen herb are used for food or therapeutic purposes in traditional medicine. This study will describe the bioactive properties of *A. scorodoprasum L. subsp. rotundum*, which belongs to the genus Allium and is known by many different names, including antidiabetic, cytotoxic and especially anti-inflammatory activities, in addition to antioxidant and antimicrobial activities, as well as its uses.
Keywords: Körmen herb, *Allium scorodoprasum subsp. rotundum*, Bioactivity properties

Giriş

Allium türü dünyanın en eski ekili bitkilerinden biri olarak kaydedilmiştir. Allium bitkilerinin organları, yüksek flavonoid, karotenoid ve klorofil seviyelerine ve düşük toksik oksijen radikal seviyelerine sahip oldukları için güçlü antioksidan özelliklere sahiptir (Ekici ve ark.,2022). Sarımsak, pırasa, frenk soğanı ve arpacık soğanı olmak üzere Allium cinsine ait yaklaşık Allium cinsi, 800'den fazla tür, 15 alt cins ve 72 bölüm içermektedir (Kılınç ve ark., 2023; Şenol ve Arslanoğlu, 2025). Allium bitkileri 25–90 cm boyunda, koyu kırmızı ve mor çiçeklere ve 2–8 mm çapında ipliksi yapraklara sahiptir (Şekil 1). Farmakolojik olarak, Allium türleri yara iyileşmesi için antiseptik ve hipotansiyonu tedavi etmek için diüretik olarak kullanılır; bitki ayrıca hepatoprotektif ve antitümör aktivitelere sahiptir (Güngör ve ark., 2023). Tıbbi ve aromatik bitkilerden birisi olan ve körmen, kaya sarımsağı, delice pırasa, vahşi sarımsak, sirmo, çatlanguş, köpek soğanı ve çoban sarımsağı gibi farklı geleneksel isimlerle bilinen Allium scorodoprasum subsp. rotundum, Alliaceae ailesinin bir üyesidir. *Allium scorodoprasum* türleri genel olarak halk arasında yabani pırasa ve sarımsak olarak değerlendirilmektedir. Allium grubunda soğan ve sarımsak familyasına ait olan *Allium scorodoprasum* yabani olması nedeniyle mevsiminde toplanan ve sahip olduğu biyoaktif bileşenler nedeniyle değerli görülen bir bitkidir. *Allium scorodoprasum* azotlu topraklarda gelişim gösteren orman içlerinden dere kenarlarına kadar yayılım gösterebilen bitki çeşidi Asya ve Avrupa'da bilinmektedir (Kazienko ve Torzewski,2019; Kılınç ve ark., 2023). *Allium scorodoprasum*'un yaprakları ve diğer kısımları çiğ veya pişmiş (kızarmış) olarak tüketilebilir ve tatlandırıcı olarak kullanılabilir. Öte yandan, *Allium scorodoprasum* halk hekimliğinde diyabet kontrolü ve görme iyileştirme için kullanılmaktadır (Ekici ve ark., 2022). Allium scorodoprasum L. (Amaryllidaceae familyası) Kuzey ve Doğu Anadolu'da yaygın olarak yetiştirilir ve peynir, yoğurt ve ekmek üretiminde kullanılmaktadır (Güngör ve ark., 2023).



Şekil 1. *Allium scorodoprasum* (a) çiçeği (b) soğanı (Anonim 2025)

Körmen bitkisi sahip olduğu sülfür bileşenleri nedeniyle aromatik bir tada sahiptir. Daha çok yerel halk tarafından tibbi amaçlarla kullanılmaktadır (Mitic ve ark., 2014). Bazı yörelerde çiğ ve pişmiş formaları yemekleri lezzetlendirmek amacıyla mutfaklarda kullanılmaktadır (Tasci ve Koca, 2016). Sağlık üzerinde etkileri kanser önleyici, tansiyon düzenleyici, karaciğer koruyucu, obezite üzerinde olumlu etkileri olan ve antimikrobiyal ve antioksidan etkileri ile sağlık açısından oldukça değerli bir bitkidir (Kurnia ve ark., 2021).

Allium scorodoprasum bitki ekstraklarının antimikrobiyal etkileri de belirlenmiştir. *Staphylococcus aureus* suşlarının yanı sıra *Candida tropicalis* ve *Candida glabrata* üzerinde antimikrobiyal etki gösteren ekstraktlar bu anlamda değerli bulunmuştur (Canlı ve ark., 2023).

Allium scorodoprasum çiçek ekstrakları ile yapılan başka bir çalışmada ise körmen çiçeklerinin fenolik ve flavanoid bakımından zengin olduğu tespit edilirken enzimlere karşı etkili olmasının yanında yara iyileştirici olarak ta kullanılabileceği belirlenmiştir (Đorđevski ve ark., 2022). *A. scorodoprasum* L.'nin farklı kısımları (soğan, gövde, çiçek) zengin fenolik içerikleri nedeniyle güçlü bir antioksidan etkiye sahiptir. *A. scorodoprasum* L. yaprakları karotenoid, flavonoid ve allisin bileşikleri içermektedir. Bitki, süperoksit dismutaz (SOD), katalaz (CAT) ve glutatyon peroksidaz (GPx) aktiviteleri ile karakterize edilir ve flavonoidler, fenolik asitler, C vitamini ve indirgenmiş glutatyon bulundurmaktadır. Ayrıca, A. scorodoprasum L. güçlü ferrik indirgeyici güce ve radikal temizleme kapasitesine sahiptir (Gungor ve ark., 2023).

Yapılan bir çalışmada Sivas/Zara bölgesinde yetiştirilen körmenlerde toplam fenolik madde, antioksidan aktivite gibi biyoaktif özellikler incelenmiştir. Çalışma sonucunda optimum ekstraksiyon prosesi ile elde edilen körmen ekstraktlarında kuarsetin, vanilik asit, kafeik asit, 2,4 hidroksibenzoik asit, elajik asit, ferulik asit, klorojenik asit, naringenin, kaempeferol, kateşin, epikateşin ve gallik asit gibi fenolik bileşenler tespit edilmiştir. Yine aynı çalışmada körmen ekstraktlarının ksantin oksidaz ve lipoksigenaz enzimlerini inhibe ettiği ve antienflamatuar etki gösterdikleri belirlenmiştir. Ayrıca yine aynı çalışmada körmenin kemik kanseri hücreleri üzerinde etkili olduğu tespit edilmiştir (Demir T., 2018).

Yapılan başka bir çalışmada ise 3 farklı yörede yetiştirilen körmen bitkilerinin yaprak ve soğan kısımlarının antioksidan madde miktarları ve antioksidan etkileri incelenmiştir. Çalışma sonucunda yaprakların soğanlarına göre daha fazla antioksidan etkiye sahip olduğu belirlenirken elde edilen bölge farklılığının yapraktaki antioksidan madde miktarı ve antioksidan aktiviteyi etkilediği belirlenmiştir (Taşcı ve ark., 2019).

Sonuç Tartışma

Körmen bitkisi dünya genelinde yayılım gösteren ve özellikle ülkemizin farklı bölgelerinde yetişen yabani bir bitkidir. Yapılan tüm çalışmalar körmen bitkisinin sağlık üzerinde olumlu etkiler oluşturuduğunu göstermektedir. Öte yandan antioksidan aktivite gibi özellikleri içine eklendikleri ürünlerde de olumlu etkiler göstereceğini ifade etmektedir. Genel olarak sarımsak gibi tüketilen bu bitki sadece yerel halk tarafından kullanılma ve yerel pazarlarda satışa sunulmaktadır. Özellikle sağlık üzerindeki etkileri düşünüldüğünde yabani bir bitki olan körmene daha çok özen gösterilmesi gerektiği tespit edilmiştir. Kurutularak baharat olarak kullanımı, ürün formülasyonlarına eklenmesi, ilaç etken madde olarak çalışılması gibi durumlar söz konusu olduğunda bahsi geçen malzemeden ve olumlu etkilerinden daha fazla faydalanılması söz konusu olabilecektir. Daha çok ürünün biyoaktif özellikleri ve sağlık üzerinde ki etkilerinin araştırıldığı çalışmalara literatürde yer almaktadır. Fakat faydaları sıralanan ve olumlu etkileri görülen körmen üzerinde daha fazla çalışma yapılması önerilmektedir.

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ENERGY EFFICIENCY AND FINANCIAL PERFORMANCE IN CHEMICAL PRODUCTION

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Abstract
The chemical industry is one of the most energy-intensive sectors globally, significantly contributing to energy consumption and greenhouse gas emissions. In the face of rising energy costs, increasing environmental regulations, and growing demand for sustainable production, energy efficiency has become both a challenge and an opportunity. This paper examines the interplay between energy efficiency measures and financial performance in chemical production. Through an analysis of technological innovations, operational practices, and financial impacts, the study illustrates that energy efficiency not only enhances environmental sustainability but also improves profitability, competitiveness, and long-term resilience for companies operating in this sector.

1. Introduction

Chemical manufacturing is a cornerstone of the global industrial economy, providing essential materials for agriculture, construction, pharmaceuticals, and countless other sectors. However, the production processes involved-particularly in petrochemical refining, polymer synthesis, and bulk commodity chemicals are notoriously energy-intensive. According to the International Energy Agency, the chemical and petrochemical industries account for approximately 10% of total global final energy consumption and about **7**% of industrial CO_2 emissions. This makes the industry a central focus in global efforts to enhance energy efficiency and reduce greenhouse gas emissions in alignment with the goals of the Paris Agreement. In this context, energy efficiency has emerged as a strategic lever not only for environmental compliance but also for enhancing financial performance and competitive advantage [1-8].

This substantial energy demand translates directly into financial and environmental costs. The volatility of global energy markets further exacerbates operational risks, particularly for producers dependent on fossil fuels. At the same time, global climate policies and carbon reduction targets are forcing industries to transition toward cleaner, more energy-efficient production methods.

The chemical industry plays a vital role in the global economy, supplying essential materials and products to sectors such as pharmaceuticals, agriculture, construction, plastics, and consumer goods. Despite its indispensable contribution to industrial growth, the chemical sector is one of the most energy-intensive branches of manufacturing. Processes such as distillation, cracking, polymerization, and drying demand vast amounts of thermal and electrical energy, making energy consumption a major operational concern and a significant driver of production costs.

Improving energy efficiency in chemical production offers a dual benefit: it reduces operational expenditures by lowering energy use and contributes to sustainability by minimizing carbon footprints. For firms operating in highly competitive and cost-sensitive environments, even marginal improvements in energy performance can translate into significant economic gains. Empirical studies have consistently shown that energy efficiency measures-such as process optimization, waste heat recovery, equipment upgrades, and digital monitoring-often yield short payback periods and long-term financial benefits.

Moreover, stakeholders including investors, regulators, and customers are increasingly scrutinizing the environmental and energy performance of manufacturers. Companies that proactively invest in energy-saving technologies often gain reputational advantages, access to preferential financing, and the ability to comply with emerging carbon pricing mechanisms and sustainability disclosure frameworks. In this respect, energy efficiency is not merely a technical or environmental consideration, but a core business strategy with measurable financial implications.

Despite the clear benefits, the chemical industry still faces several barriers to widespread implementation of energy efficiency measures. These include high upfront investment costs, lack of expertise, fragmented incentives, and operational risks associated with modifying established production processes. Particularly in small and medium-sized enterprises (SMEs), limited capital and technical capacity can delay or prevent the adoption of best-available technologies. Therefore, a comprehensive understanding of both the technical potential and the financial dynamics of energy efficiency is essential for informed decision-making [1-17].

This paper aims to explore the relationship between energy efficiency and financial performance within the context of chemical production. Specifically, it seeks to:

Examine the types of energy-efficient technologies and practices currently used in the chemical sector. Evaluate the economic benefits and cost-saving potential of these measures. Discuss real-world examples and case studies from leading companies. Identify key challenges and opportunities associated with implementing energy efficiency at scale. By integrating insights from engineering, environmental science, and industrial economics, the paper provides a multi-dimensional perspective on how energy efficiency can serve as a tool for achieving sustainable and profitable growth in the chemical industry. The ultimate goal is to demonstrate that energy optimization is not only environmentally responsible but also a financially sound investment for both large and small chemical producers.

2. Development

2.1. Energy use in chemical production

Chemical plants consume energy in various forms-electricity, steam, fuel, and heat-for processes such as distillation, drying, cracking, and polymerization. Many of these operations are continuous and high-temperature, requiring stable, uninterrupted energy supply.
Energy intensity is often measured in terms of energy use per unit of output (e.g., GJ/ton of product). Lowering energy intensity requires both operational improvements and capital investments in efficient technologies. For example, the use of multi-effect distillation or membrane separation systems can significantly reduce the thermal energy required in solvent recovery or dehydration processes [2, 3, 7].

2.2 Energy-Efficient technologies

Recent advancements have made several energy-saving technologies accessible and viable for the chemical sector:

Heat Integration & Pinch Analysis: These methods help optimize heat exchange networks to reuse energy within the process, significantly lowering fuel consumption.

Advanced Process Controls (APCs): By integrating sensors, real-time analytics, and automation, APCs ensure that equipment operates at optimal conditions, reducing unnecessary energy usage.

High-Efficiency Motors and Drives: Replacing legacy mechanical systems with variable speed drives can result in energy savings of up to 30% in pumping and ventilation systems.

Catalyst Innovations: Modern catalysts reduce activation energy requirements in chemical reactions, thus cutting down on energy inputs while increasing yield [1-10].

2.3 Financial impacts of energy efficiency

The business case for energy efficiency is compelling. Investments in energy-saving equipment often have short payback periods-ranging from one to five years-and yield long-term operational cost savings. In highly competitive sectors where margins are slim, such savings can be transformative.

Key financial benefits include:

Reduced Operating Costs: Direct savings in energy consumption translate to improved profit margins.

Return on Investment (ROI): Energy efficiency investments often outperform traditional capital investments in terms of ROI due to their immediate impact on operating costs.

Improved Credit Ratings and Investor Confidence: Companies that demonstrate responsible energy management and sustainability practices attract favorable financing terms and greater investor interest.

Regulatory Incentives: Many governments provide tax credits, grants, and carbon trading benefits to companies that implement certified energy efficiency programs [2, 17].

2.4 Case Studies

Case Study: BASF SE

BASF has implemented integrated production systems known as "Verbund" operations, where waste heat and by-products from one process are reused in another. This approach has reduced the company's energy demand by approximately 20%, resulting in savings of over €1 billion in the past decade.

Case Study: Dow Chemical Dow's 2020 Energy Efficiency Program included more than 2,000 individual projects. The company reported cumulative savings of $9 billion since the program's inception in 1994, with many projects offering payback periods of less than three years [1-17].

2.5 Barriers to implementation

Despite the advantages, several barriers hinder widespread adoption of energy-efficient technologies:

- High Initial Costs: Many solutions require capital expenditures, which may deter short-term-focused firms.
- Lack of Expertise: Especially in small and medium-sized enterprises (SMEs), there may be a skills gap in energy management and process optimization.
- Risk Aversion: Management may avoid unproven or complex technologies due to perceived risks.
- Split Incentives: In facilities where operations and infrastructure are managed separately, the benefits of investment may not accrue to those who bear the costs.

Overcoming these challenges requires policy support, capacity building, and alignment of business incentives [2-4].

3. Conclusion

Energy efficiency is not merely an environmental goal but a financial and strategic imperative for chemical manufacturers. As demonstrated by global industry leaders, systematic energy optimization can lead to substantial cost savings, improved competitiveness, and enhanced corporate reputation.

The road to energy-efficient chemical production, however, is not without obstacles. Addressing financial, technical, and organizational barriers will be essential. Future advancements in digitalization, AI-driven process control, and clean energy integration will further enable companies to transition toward more sustainable models of operation.

In conclusion, the integration of energy efficiency into corporate strategy offers a dual benefit: reducing environmental impact while strengthening financial performance. As the global economy increasingly rewards low-carbon and cost-effective operations, companies that act early will be better positioned to lead.

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GRAPHENE BASED SENSOR TECHNOLOGY

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Abstract

Graphene, a one-atom-thick planar sheet of carbon atoms arranged in a honeycomb lattice, has emerged as a revolutionary nanomaterial due to its remarkable mechanical strength, electrical conductivity, thermal stability, and large surface area. These unique characteristics have made graphene a promising candidate for the development of high-performance sensors across multiple domains, including gas detection, biosensing, mechanical strain monitoring, and chemical analysis. This paper investigates the material properties of graphene relevant to sensing applications, explores various sensor types enhanced by graphene, evaluates the challenges associated with its integration into commercial products, and discusses future directions for research and development. The study concludes that graphene-based sensors hold significant potential to transform sensing technologies, with the caveat that production, integration, and reliability challenges must be addressed.

1. Introduction

Sensor technology has become increasingly important in modern society, with applications spanning healthcare, environmental monitoring, industrial automation, homeland security, and wearable electronics. The demand for miniaturized, highly sensitive, fast-response, and low-power sensors is pushing the limits of conventional materials and device architectures. In this context, graphene has gained considerable attention as an enabling material due to its unique physical and chemical properties.

First isolated in 2004 by Andre Geim and Konstantin Novoselov, graphene consists of a single layer of carbon atoms arranged in a two-dimensional hexagonal lattice. Its electrical conductivity surpasses that of copper, its thermal conductivity rivals that of diamond, and its surface-to-volume ratio provides exceptional interaction with analytes, making it highly sensitive to changes in its surrounding environment. These properties make graphene an ideal material for sensing applications, where performance is largely determined by signal transduction efficiency and surface reactivity.

The field of nanotechnology is advancing quickly, and carbon-based nanocomposites have become a key research focus. These materials are notable for their nanoscale size and carbon content, which confer distinctive properties suitable for diverse applications. Among these, breath sensors stand out as a promising technology that could transform medical diagnostics and environmental monitoring [1]. Incorporating carbon-based nanocomposites into sensor technology may improve their sensitivity and selectivity, easing the identification of trace elements in breath samples. These sensors provide a non-invasive, real-time examination of a patient's breath in order to identify a variety of health issues or track the exposure to environmental pollutants [2]. This ability led to early diagnosis and treatment, which is a significant advantage.

Additionally, breath sensors are an essential part in the field of environmental monitoring. Toxic chemicals and contaminants in the atmosphere, which may have substantial effects on the health of people, are detected by these instruments [3]. Prompt reactions to environmental risks are made possible by the capability of monitoring air quality in real time [4, 5]. Breath sensors are essential in the process of identifying hazardous substances and toxins that are present in the air. These devices allow quick responses to environmental concerns, which protects public health in real time.

Nanocomposites often show enhanced strength, stiffness, toughness, and durability compared to their base materials. The integration of nanoparticles can result in a substantial improvement in mechanical properties, including tensile strength and the modulus of elasticity [6-9].

The electrical conductivity of nanocomposites can be tailored by the addition of conductive nanofillers[10, 11]. This makes them suitable for a range of applications including sensors, actuators, and energy storage devices [12, 13]. Nanocomposites can exhibit improved thermal stability, flame retardancy and exhibit distinct chemical reactivity compared to its bulk materials [14, 15] and have a high surface-to-volume ratio, resulting in enhanced activity at catalytic sites[16-18]. The high surface area provides an effective barrier to heat and flame propagation[19, 20].

Carbon-based composites provide a multitude of benefits, including a large surface area, porosity that may altered, chemical stability, biocompatibility, and a cheap cost. Carbon nanotubes (CNTs), graphene, carbon dots (CDs), carbon fibers (CFs), activated carbon (AC), polymers, and carbon composites are some of the numerous types of carbon-based materials that may be divided into several categories [21-23].

This paper reviews the role of graphene in sensor technology, categorizes the types of sensors that have successfully incorporated graphene or its derivatives, and evaluates the current state of the field in both research and industry.

2. Development

2.1. Structure and properties of graphene

Graphene is a two-dimensional material consisting of a single layer of carbon atoms arranged in a hexagonal lattice. Its electrical conductivity, flexibility, and optical transparency make it suitable for a wide range of electronic applications. Additionally, its high sensitivity to environmental changes makes it ideal for sensor applications. Graphene's suitability for sensor applications is derived from several key material properties:

Electrical Conductivity*:* Graphene exhibits high carrier mobility and low electrical noise, enabling precise detection of small changes in charge. ***Large Surface Area****:* One gram of graphene can cover up to 2,630 m², offering a massive active surface for analyte adsorption.

Mechanical Strength*:* With a tensile strength of ~130 GPa, graphene can withstand mechanical deformation, making it ideal for flexible and wearable sensors. ***Chemical***

Tunability*:* Graphene can be functionalized with a wide range of chemical groups to enhance selectivity and specificity. These attributes enable the development of sensors with high sensitivity, fast response times, and broad dynamic ranges [24-26].

2.2. Types of Graphene-Based Sensors

Gas Sensors

Graphene's sensitivity to gas molecules such as NO_2, NH_3, CO, and H_2 makes it an excellent candidate for gas sensing applications. Gas molecules adsorbed onto the graphene surface act as electron donors or acceptors, altering the material's electrical conductivity. Pristine graphene, reduced graphene oxide (rGO), and doped or functionalized graphene are used to increase selectivity and response time. *Example*: A graphene-based NO_2 sensor showed detection limits below 1 ppb at room temperature, outperforming traditional metal oxide sensors [24-30].

Biosensors

In biosensors, graphene provides a biocompatible and conductive platform for immobilizing biomolecules such as enzymes, antibodies, and DNA. Graphene Field Effect Transistors (GFETs) have been used to detect glucose, dopamine, cancer biomarkers, and even viral particles like SARS-CoV-2. *Example*: Graphene oxide functionalized with specific antibodies has been used to detect prostate-specific antigen (PSA) with high accuracy [24-30].

Pressure and Strain Sensors

Due to its mechanical flexibility, graphene is used in wearable sensors that respond to strain, pressure, and deformation. These sensors are often fabricated as graphene-polymer composites. *Example*: A flexible graphene-based pressure sensor integrated into a wearable band can detect pulse rate and body movement in real time [24-30].

Chemical and Electrochemical Sensors

Graphene's high electrochemical surface area makes it suitable for sensors that detect pH, ions, and organic molecules in liquid phases. *Example*: Graphene-modified electrodes have been employed in detecting heavy metal ions such as Pb^{2+} and Cd^{2+} in water samples [24-30].

2.3. Fabrication Techniques

Key methods for integrating graphene into sensors include:
Chemical Vapor Deposition (CVD): Produces high-quality, large-area graphene films, suitable for electronics and flexible sensors. Liquid-Phase Exfoliation: Cost-effective, used for composite materials and coatings. Reduction of Graphene Oxide (GO): Scalable method for producing functionalized graphene-like materials with oxygen-containing groups. Each method has trade-offs in terms of purity, cost, scalability, and compatibility with substrates [28-30].

2.4. Challenges in Commercialization

While graphene shows promise in laboratory settings, several challenges remain: *Reproducibility*: Variability in graphene quality and structure leads to inconsistent sensor performance. *Integration with Electronics*: Interfacing graphene with silicon-based circuitry requires complex fabrication steps. *Long-Term Stability*: Environmental exposure can degrade graphene's sensing properties over time. *Scalability and Cost*: High-quality graphene is expensive and difficult to produce in bulk, limiting commercial viability. Efforts to standardize graphene materials and sensor designs are ongoing and crucial for commercial adoption [28-30].

3. Conclusion

Graphene has demonstrated exceptional capabilities as a material for next-generation sensors across various applications. Its unique combination of electrical, mechanical, and chemical properties enables the creation of sensors that are faster, smaller, more sensitive, and more energy-efficient than their conventional counterparts.
Despite its promise, real-world deployment of graphene-based sensors faces obstacles such as manufacturing consistency, integration complexity, and cost-effectiveness. Addressing these challenges requires multidisciplinary collaboration among material scientists, engineers, and industry stakeholders.
Future developments, particularly in the areas of scalable graphene production, sensor miniaturization, and hybrid material integration, are expected to drive the widespread adoption of graphene sensors. As these advancements mature, graphene is poised to play a transformative role in fields ranging from personalized healthcare to environmental protection and smart manufacturing.

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ARONİA BİTKİLERİNİN KANSER AKTİVİTELERİ ÜZERİNE ETKİLERİ

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ÖZET

Aronia melanocarpa (siyah aronya), son yıllarda fitokimyasal zenginliği ve güçlü antioksidan kapasitesi nedeniyle fonksiyonel gıda ve tamamlayıcı tıp alanlarında dikkat çeken bir bitki türüdür. Yapılan araştırmalar, aronia meyve ve yaprak ekstraktlarının çeşitli kanser türleri üzerinde antikanser potansiyele sahip olduğunu göstermektedir. Bu derlemede, *Aronia melanocarpa*'nın farklı kanser hücre hatları üzerindeki biyolojik etkileri değerlendirilmiştir. Meme, kolon, beyin, mesane ve serviks kanserlerine yönelik yapılan in vitro çalışmalar; hücre proliferasyonunun baskılandığını, apoptozun uyarıldığını ve epigenetik düzenleyici yolların (ör. PTEN ve TIMP3 ekspresyonu, hTERT düzeyleri, MMP genleri) etkilendiğini ortaya koymuştur. Ayrıca, bu etkilerin seçici sitotoksisiteye sahip olduğu ve sağlıklı hücrelere daha az zarar verdiği bildirilmiştir. Elde edilen bulgular, *Aronia melanocarpa*'nın antikanser özelliklerinin altında yatan mekanizmaların daha fazla in vivo ve klinik çalışmayla desteklenmesi gerektiğini göstermektedir. Bu bağlamda aronya, doğal kaynaklı kanser önleyici veya tedaviye yardımcı ajanlar arasında önemli bir aday olarak değerlendirilmektedir.

EFFECTS OF ARONIA PLANTS ON CANCER ACTIVITIES

ABSTRACT

Aronia melanocarpa (black chokeberry) has attracted growing interest in recent years due to its rich phytochemical composition and strong antioxidant capacity, making it a promising candidate in the fields of functional foods and complementary medicine. Recent studies have demonstrated that extracts derived from Aronia fruits and leaves exhibit significant anticancer potential against various cancer types. This review evaluates the biological effects of *Aronia melanocarpa* on different cancer cell lines, including breast, colon, brain, bladder, and cervical cancers. In vitro studies have shown that Aronia extracts suppress cell proliferation, induce apoptosis, and modulate key epigenetic and molecular pathways—such as the expression of tumor suppressor genes (e.g., PTEN and TIMP3), hTERT protein levels, and matrix metalloproteinases (MMPs). Moreover, these effects were reported to exhibit selective cytotoxicity, with minimal impact on healthy cells. The findings suggest that while *Aronia melanocarpa* shows promising anticancer activity, further in vivo and clinical studies are necessary to fully understand its therapeutic potential. In this context, Aronia stands out as a notable natural candidate for cancer prevention and adjuvant therapy.

GİRİŞ

Günümüzde hastalıkların yalnızca tedavisine değil, aynı zamanda önlenmesine yönelik yaklaşımlar da giderek önem kazanmaktadır. Bu bağlamda, doğal kaynaklı biyoaktif bileşenlerin sağlık üzerindeki koruyucu etkilerine odaklanan çalışmalar artış göstermiştir. Özellikle fitokimyasal içerikleri zengin olan meyve ve sebzeler, hem fonksiyonel gıda bileşenleri hem de destekleyici tedavi unsurları olarak değerlendirilmektedir (Jurikova et al., 2017).

Günlük diyette sıkça tüketilen üzümsü (berry tipi) meyveler; lezzetli, düşük kalorili, yüksek lif içeriğine sahip ve zengin polifenol profilleriyle öne çıkmaktadır. Bu meyveler arasında *Fragaria vesca* (yabani çilek), *Rubus fruticosus* (böğürtlen), *Rubus idaeus* (ahududu), *Ribes nigrum* (siyah frenk üzümü), *Vaccinium myrtillus* (yaban mersini) ve *Sambucus nigra* (mürver) gibi türler yer almaktadır. Kimyasal yapıları nedeniyle bu meyveler güçlü antioksidan özellikler göstermekte ve oksidatif stresle ilişkili birçok dejeneratif hastalığın önlenmesi ve tedavisinde potansiyel faydalar sunmaktadır (Kulling & Rawel, 2008).

Bu meyveler arasında yer alan *Aronia melanocarpa* (siyah aronya), *Rosaceae* (gülgiller) familyasına ait, çalı formunda bir bitkidir. Genellikle meyve üretimi amacıyla kültüre edilen *Aronia* türleri, doğal olarak Kuzey Amerika ve Kanada' nın doğu bölgelerinde yetişmektedir. Avrupa'ya ilk kez 20. yüzyılın başlarında Almanya üzerinden giriş yapmış, ardından Rusya ve diğer Doğu Avrupa ülkelerine yayılmıştır. 2–3 metreye kadar boylanabilen bu çalımsı bitkiler, Mayıs–Haziran aylarında çiçek açmakta ve olgunlaştıklarında kırmızı veya siyah renkte, 6–13 mm çapında ve 0.5–2 g ağırlığında meyveler vermektedir (Kaskoniene et al., 2009).

Aronya meyvesi, sahip olduğu yüksek polifenol, antosiyanin ve flavonoid içeriğiyle fonksiyonel gıda araştırmalarında önemli bir yere sahiptir. Bu bileşenlerin sağlık üzerindeki etkilerinin daha iyi anlaşılması, aronya ve benzeri meyvelerin gıda endüstrisinde daha yaygın kullanılmasını sağlayabilir. *Aronia* meyveleri, zengin kimyasal bileşimleri sayesinde yalnızca besleyici bir gıda olarak değil, aynı zamanda geleneksel bitkisel tedavi uygulamalarında da kullanılmaktadır. Özellikle Rusya ve bazı Doğu Avrupa ülkelerinde, *Aronia* meyvelerinin antihipertansif ve antiaterosklerotik etkileri nedeniyle uzun yıllardır tıbbi amaçlı kullanıldığı bilinmektedir (Kokotkiewicz, A. et.al., 2010). Son yıllarda yapılan araştırmalarda, *Aronia melanocarpa* meyvelerinin güçlü antioksidan özelliklerinin yanı sıra antiinflamatuvar, antidiyabetik, antikanser, antimutajenik ve antibakteriyel aktiviteler sergilediği gösterilmiştir. Ayrıca obezite, kardiyovasküler hastalıklar ve otoimmün rahatsızlıklar gibi çeşitli kronik hastalıkların önlenmesi ve tedavisinde potansiyel terapötik etkileri de ortaya konmuştur (Kulling & Rawel, 2008; Jurikova et al., 2017). Bu makalede, Türkiye'de ve dünya genelinde fonksiyonel bir besin olarak kullanımı giderek artan *Aronia* meyveleri üzerine yapılan antikanser aktiviteye yönelik bilimsel çalışmalar derlenmiştir. Elde edilen bulguların, *Aronia* bitkisinin kültüre alınması, doğrudan gıda olarak tüketimi ya da işlenmiş ürünler hâlinde kullanımı konularında bilgi altyapısı sağlaması ve literatüre katkı sunması amaçlanmaktadır.

GELİŞME-LİTERATÜR

2024 yılında gerçekleştirilen bir çalışmada, *Aronia melanocarpa* meyve kabuklarının hem in vitro hem de in vivo meme kanseri modellerinde antikanser etkileri değerlendirilmiştir. Bu çalışmada, aronia ekstraktının tümör hacmini azalttığı, hücre çoğalmasını baskıladığı, apoptozu indüklediği ve kanser kök hücre belirteci CD133'ün ekspresyonunu düşürdüğü gözlemlenmiştir. Ayrıca, epigenetik düzeyde histon modifikasyonları, miRNA ekspresyonları ve tümör baskılayıcı genlerin (PTEN, TIMP3) metilasyon durumlarında olumlu değişiklikler tespit edilmiştir (Dvorska D. Et. al.,2024).

Türkiye'de yapılan bir başka çalışmada ise, *Aronia melanocarpa* meyve ekstraktlarının MCF-7 (meme kanseri) ve HeLa (servikal kanser) hücre hatları üzerindeki sitotoksik etkileri incelenmiştir. Bu çalışmada, aronia ekstraktlarının kanser hücrelerinin canlılığını azalttığı, ancak sağlıklı hücreler üzerinde belirgin bir toksik etki göstermediği rapor edilmiştir (Sönmez Gürer, E., & Altıntaş, A., 2024).

U373 glioblastoma hücre hattı üzerinde yapılan bir çalışmada, *Aronia melanocarpa* polifenollerinin apoptozu indüklediği ve hücre iskeletiyle ilişkili MMP genlerinin ekspresyonunu azalttığı bulunmuştur. Bu etkiler, tümör hücrelerinin invazyon ve metastaz potansiyelini azaltabileceğini göstermektedir (Abdullah T. et. al., 2012).

Yapılan bir çalışmada, *Aronia melanocarpa* ekstraktlarının HT-29 kolon kanseri hücre hattı üzerindeki antiproliferatif etkileri ve hTERT protein düzeyleriyle ilişkisi incelenmiştir. Sonuçlar, aronia ekstraktlarının hücre canlılığını azaltırken, hTERT protein düzeylerini de düşürdüğünü göstermiştir (Caliskan, Z. et.al. 2023).

Polonya'da yapılan bir başka çalışmada ise, aronia yaprak ekstraktlarının Caco-2 kolon adenokarsinom hücre hattı üzerindeki sitotoksik ve DNA hasarına yol açan etkileri değerlendirilmiştir. Ekstraktların, hücrelerde morfolojik değişikliklere ve DNA hasarına neden olduğu, ancak düşük konsantrasyonlarda DNA onarımını destekleyebileceği belirtilmiştir (Efenberger-Szmechtyk M. et.al., 2020).

2024 yılında yayımlanan bir çalışmada, *Aronia melanocarpa* suyunun T24 mesane kanseri hücre hattı üzerindeki etkileri incelenmiştir. Aronia suyunun, kanser hücrelerinin canlılığını azaltırken, normal hücreler üzerinde daha az toksik etki gösterdiği rapor edilmiştir. Bu etkiler, aronia suyunun yüksek antioksidan kapasitesi ve polifenol içeriğine bağlanmıştır (Novak D., 2025).

Aronia melanocarpa ekstraktlarının, HL-60 promiyelositik lösemi hücre hattı, A549 akciğer kanseri hücre hattı ve HeLa servikal kanser hücre hattı üzerinde de antiproliferatif etkiler gösterdiği bildirilmiştir. Bu etkiler, ekstraktların zengin polifenol içeriğiyle ilişkilendirilmiştir (Efenberger-Szmechtyk M.et.al., 2020).

SONUÇ

Elde edilen bulgular, Aronia melanocarpa meyvesinin hem fitokimyasal açıdan zengin bir profil sunduğunu hem de çeşitli biyolojik etkileri sayesinde fonksiyonel gıda potansiyeline sahip olduğunu ortaya koymaktadır. Özellikle antioksidan ve kardiyoprotektif etkiler bakımından yapılan çalışmalar, aronya meyvesinin düzenli tüketiminin oksidatif stres kaynaklı hastalıkların önlenmesinde rol oynayabileceğini göstermektedir. Bununla birlikte, mevcut çalışmaların büyük çoğunluğu in vitro ya da hayvan modellerine dayalıdır; dolayısıyla insanlar üzerinde yapılacak kontrollü klinik çalışmalarla bu etkilerin doğrulanması önem arz etmektedir. *Aronia melanocarpa* meyveleri, yüksek polifenol içeriği ve güçlü antioksidan etkileri sayesinde hem sağlıklı bireyler için koruyucu bir besin, hem de çeşitli hastalıkların destekleyici tedavisinde kullanılabilecek fonksiyonel bir bileşen olarak öne çıkmaktadır. Literatürde yer alan bulgular, bu meyvenin antiinflamatuvar, antidiyabetik, kardiyovasküler koruyucu ve antikanser etkiler sunduğunu göstermektedir. Bu çalışma, Türkiye'de henüz sınırlı düzeyde tanınan Aronia bitkisinin yaygınlaşması ve yerli üretim potansiyelinin değerlendirilmesi açısından da bir ön bilgi kaynağı olmayı amaçlamaktadır. Gelecekte yapılacak insan temelli klinik çalışmalar, bu bulguların daha geniş kitlelere uygulanabilirliğini değerlendirme açısından kritik öneme sahiptir.

Aronia melanocarpa, çeşitli kanser türleri üzerinde antiproliferatif, apoptoz indükleyici ve epigenetik modülatör etkiler gösteren biyoaktif bileşenler içermektedir. Ancak, bu etkilerin klinik uygulamalara yansıtılabilmesi için daha fazla in vivo ve klinik çalışmaya ihtiyaç vardır.

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MOLEHİA BİTKİSİNİN KANSER AKTİVİTELERİ ÜZERİNE ETKİLERİ

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ÖZET

Corchorus olitorius (molokhia), çeşitli kanser türlerine karşı ümit verici antikanser etkileri göstermiştir. İn vitro çalışmalar, bitki özlerinin hücre çoğalmasını engellediğini, apoptozu indüklediğini ve sağlıklı hücrelere karşı minimal toksisite ile kanser hücrelerini seçici olarak hedef aldığını göstermiştir. Bu biyolojik aktiviteler, bitkinin zengin fenolik ve flavonoid bileşikleri içeriğine atfedilmektedir. Etanol ve metanol özleri karaciğer (HepG2), meme (MCF-7), akciğer (A549), kolon (Colo-320, Colo-741), melanom (A-375), mide (AGS) ve pankreas (SUIT-2) kanser hücre hatları üzerinde sitotoksik etkiler göstermiştir. Mekanistik analizler, apoptozun kaspaz aktivasyonu, sitokrom c salınımı ve pro- ve anti-apoptotik proteinlerin modülasyonunu içeren mitokondriyal yollarla indüklendiğini ortaya koymaktadır. Ayrıca, klorojenik asit ve izokersetin gibi belirli biyoaktif bileşikler antiproliferatif ve anti-anjiyojenik etkiler göstermiştir. Her ne kadar in vitro sonuçlar ümit verici olsa da, *Corchorus olitorius*' un doğal bir antikanser ajanı olarak terapötik potansiyelini doğrulamak için daha fazla in vivo ve klinik çalışmaya ihtiyaç vardır.

EFFECTS OF MOLEHIA PLANT ON CANCER ACTIVITIES

ABSTRACT

Corchorus olitorius (molokhia) has demonstrated promising anticancer effects against various cancer types. In vitro studies have shown that plant extracts inhibit cell proliferation, induce apoptosis, and selectively target cancer cells with minimal toxicity to healthy cells. These biological activities are attributed to the plant's rich content of phenolic and flavonoid compounds. Ethanol and methanol extracts have exhibited cytotoxic effects on liver (HepG2), breast (MCF-7), lung (A549), colon (Colo-320, Colo-741), melanoma (A-375), gastric (AGS), and pancreatic (SUIT-2) cancer cell lines. Mechanistic analyses reveal that apoptosis is induced via mitochondrial pathways, involving caspase activation, cytochrome c release, and modulation of pro- and anti-apoptotic proteins. Furthermore, certain bioactive compounds such as chlorogenic acid and isoquercetin have shown antiproliferative and anti-angiogenic effects. Although the in vitro results are promising, further in vivo and clinical studies are needed to confirm the therapeutic potential of *Corchorus olitorius* as a natural anticancer agent.

GİRİŞ

Corchorus olitorius L., *Malvaceae* familyasına ait, *Corchorus* cinsi içinde yer alan otsu bir bitkidir. Genellikle tropikal ve subtropikal bölgelerde yetişmektedir. Bitkinin anavatanı konusunda farklı görüşler bulunmakta olup, bazı araştırmacılar Asya, bazıları ise Afrika kökenli olduğunu belirtmektedir. *Corchorus* cinsi içerisinde yaklaşık 40 ila 100 tür bulunduğu bildirilmektedir; ancak bu türler arasında yalnızca *Corchorus olitorius L.* ve *Corchorus capsularis L.*, dünya genelinde lif üretimi amacıyla yaygın olarak kullanılmaktadır.

Corchorus olitorius, Akdeniz Havzası ve Orta Doğu ülkelerinde (Mısır, Lübnan, Filistin, Ürdün, Suriye, Tunus ve Kıbrıs) yaygın olarak kullanılmaktadır. Bu bölgelerde bitkinin tohumları çeşni, taze yaprakları sebze, kurutulmuş yaprakları ise bitki çayı olarak tüketilmektedir. Yapraklarından hazırlanan yemek olan "Molehiya", Kıbrıs' ta hem Türk hem de Arap mutfağının geleneksel yemeklerinden biridir (Tuncer ve Ummuhan, 2017). Ayrıca Arap mutfağında "Molukhyia" veya "Molokhia" adıyla anılan bu yapraklar, çorbalarda kıvam arttırıcı olarak da kullanılmaktadır (Chigurupati ve ark., 2020).

Corchorus olitorius yaprakları zengin bir fitokimyasal içeriğe sahiptir. Bu içerikte; flavonoidler, saponinler, tanenler, steroidler, terpenler, alkaloidler, glikozitler ve fenolik bileşikler yer almaktadır. Yapılan analizler, yaprakların protein içeriğinin, gövde ve meyve kısımlarına göre daha yüksek olduğunu ortaya koymuştur. Buna karşılık, ham yağ oranı gövde ve meyvelerde daha fazladır. Genel olarak, *Corchorus olitorius*' un yaprakları, gövde ve meyvelerine kıyasla daha yüksek mineral değerleri içermektedir (Ndlovu ve Afolayan, 2008; Orieke ve ark., 2018; Ürüşan ve ark., 2022).

Tablo 1: *Corchorus olitorius L.*'in besin maddesi içeriği (Soykut G.et.al., 2025)

Besin Ogesi	Birim	Miktar/100 g
Su	g	87,72
Enerji	kkal/kJ	34/142
Protein	g	4,65
Total Lipit	g	0,25
Karbonhidrat	g	5,80
Kül	g	1,58
Kalsiyum	mg	208
Demir	mg	4,76
Magnezyum	mg	64
Fosfor	mg	83
Potasyum	mg	559
Sodyum	mg	8
Çinko	mg	0,79
Bakır	mg	0,255
Manganez	mg	0,123
Selenyum	µg	0,9
C vitamini	mg	37
Tiamin	mg	0,133
Riboflavin	mg	0,546
Niasin	mg	1,260
B_6 vitamini	mg	0,600
Folat	µg	123
A vitamini (RE)	µg	278

GELİŞME-LİTERATÜR

Corchorus olitorius yapraklarının etanolik ekstraktı, HepG2 karaciğer kanseri hücreleri üzerinde anlamlı sitotoksik etki göstermiştir. Ekstraktın mitokondriye bağlı bir yolla apoptozu indüklediği, bu süreçte kaspaz-3 ve -9 aktivasyonu, PARP proteininin parçalanması ve sitokrom c salınımının gerçekleştiği tespit edilmiştir. Ayrıca bu etkilerin, sağlıklı karaciğer hücreleri üzerinde toksik olmadığı bildirilmiştir (Li C.et.al., 2012).

Metanolik ekstraktlar, MCF-7 (meme) ve A549 (akciğer) kanser hücrelerinde apoptozu indüklemiştir. Bu etki, kaspaz-3 aktivasyonu, Bcl-2 protein inhibisyonu ve DNA hasarı ile ilişkilendirilmiştir. MTT analizinde, IC_{50} değerleri sırasıyla 20 µg/mL (MCF-7) ve 12.45 µg/mL (A549) olarak belirlenmiştir. (Alshabi, A.et.al., 2022).

Diklorometan ve sulu ekstraktlar, primer (Colo-320) ve metastatik (Colo-741) kolon adenokarsinom hücrelerinde apoptozu indüklemiştir. Kaspaz-3, sitokrom c ve FasL proteinlerinin ekspresyon düzeylerinde artış gözlemlenmiştir. TUNEL testi, DNA fragmantasyonunu doğrulamıştır. Metastatik hücre hattı (Colo-741), ekstraktlara daha duyarlı bulunmuştur (Soykut G.et.al., 2025).

Sulu ekstrakt ve içeriğindeki klorojenik asit (CGA) ile izokuersetin (IQ), A-375 (melanom), AGS (mide) ve SUIT-2 (pankreas) kanser hücrelerinde antiproliferatif ve anti-anjiyogenik etkiler göstermiştir. CAM (chorioallantoic membrane) modelinde, tümör anjiyogenezisi ve büyümesi anlamlı şekilde inhibe edilmiştir (Tosoc, J. P. S.et.al., 2021).

C. olitorius yaprak ekstraktı, liposomal taşıyıcı sistemle formüle edilerek lösemi hücre hatlarında (AML ve diğerleri) test edilmiştir. Liposomal formülasyon, saf fitole kıyasla daha düşük konsantrasyonlarda daha yüksek antiproliferatif etki göstermiştir. Bu, fitolün biyoyararlanımının artırılabileceğini göstermektedir (Shariare MH.et.al., 2021).

Nijerya kaynaklı bir çalışmada, metanolik ekstrakttan izole edilen iki polifenolik bileşik (Methyl-1,4,5-tri-O-caffeoyl quinate ve trans-3-(4-Hydroxy-3-methoxyphenyl)acrylic anhydride), HeLa, HL-460 ve PC-3 kanser hücre hatlarında sitotoksik etki göstermiştir. Bu bileşiklerin, MMP-9, FGFR2 ve EGFR gibi tümörle ilişkili hedef proteinlere karşı yüksek bağlanma afinitesi gösterdiği belirlenmiştir (Taiwo BJ.et.al., 2016).

Bir çalışmada, *C. olitorius* etanolik ekstraktı, MCF-7 meme kanseri hücre hattında 50 ve 100 µg/mL konsantrasyonlarında hücre canlılığını hafifçe azaltmıştır. Ancak, daha düşük konsantrasyonlarda etkili olmamış ve daha uzun inkübasyon sürelerinde hücre canlılığında artış gözlemlenmiştir. Bu durum, ekstrakt içeriğindeki kuersetin gibi bileşiklerin östrojen reseptörleriyle etkileşimiyle açıklanabilir (Soykut G.et.al., 2025).

SONUÇ

Corchorus olitorius, içerdiği biyoaktif bileşenler sayesinde çeşitli kanser türleri üzerinde antiproliferatif, apoptotik ve anti-anjiyogenik etkiler göstermektedir. Özellikle klorojenik asit, izokuersetin ve fitol gibi bileşikler, bu etkilerin temelini oluşturmaktadır. Ancak, bazı durumlarda (örneğin, östrojen reseptör pozitif meme kanseri) dikkatli değerlendirme gerekmektedir. Bu bulgular, *C. olitorius*' un fitoterapötik ajan olarak potansiyelini ortaya koymakta olup, daha fazla in vivo ve klinik çalışmayla desteklenmesi gerekmektedir.

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DEVELOPMENT OF ADHESIVES CONTAINING POLY (GLYCIDYL METHACRYLATE-CO-METHYL METHACRYLATE) COPOLYMER AND INVESTIGATION OF THE EFFECT OF HEAT-TREATED BORIC ACID ON THEIR ADHESION PERFORMANCE

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Abstract
In this study, poly(glycidyl methacrylate-co-methyl methacrylate) copolymer was synthesized by free radical polymerization technique. The composite form of the synthesized copolymer was prepared with boric acid subjected to heat treatment at different temperatures. It is aimed to elucidate the structure of poly(glycidyl methacrylate-co-methyl methacrylate) copolymer synthesized by free radical polymerization method. The adhesion performance of composite polymers at the aluminum-aluminum interface and the mechanical properties of the joints they form were examined in detail. The properties of the synthesized composites were characterized by Fourier Transform Infrared Spectroscopy (FTIR) The adhesion performance of the composite polymers on the aluminum-aluminum interface was investigated by hot pressing method. It is aimed to strengthen metal-metal interfacial interactions with these synthesized copolymers and composites and to investigate the structural, crystalline, morphological and mechanical properties of these composites in detail.
Keywords: Glycidyl mecatilate, Polymer composites, Calcined boric acid, Mechanical Testing of Adhesives.

1.INTRODUCTION

Adhesive technologies have become an important research focus in recent years to overcome the limitations of traditional joining methods (welding, rivets, bolts) such as material heterogeneity, weight increase and corrosion risk. The increasing use of lightweight materials (aluminum, composites), especially in the aerospace, automotive and electronics industries, necessitates the development of adhesives with high strength, thermal stability and resistance to environmental factors (Banea et al., 2014; Machado et al., 2018). In this context, copolymers containing epoxy groups are frequently preferred in adhesive formulations due to their crosslinking ability and flexibility of chemical modification. Copolymers such as poly(glycidyl methacrylate-co-methyl methacrylate) [P(GMA-co-MMA)] increase the adhesion strength in resin-based systems with epoxy functionality, while the rigid structure of methyl methacrylate provides thermomechanical stability (Ratna, 2003). However, the degradation of adhesion performance under high temperature and dynamic loads on metal surfaces (especially aluminum) is one of the limiting factors of these systems. To overcome this problem, composite materials are being developed by adding inorganic additives (nanoparticles, fibers, boron compounds) to the adhesive matrix. For example, Khalili et al. (2008) experimentally proved that the addition of glass fibers and micropowders to epoxy resins increases the bond strength by 30-40%. Similarly, Udatha et al. (2020) reported that natural fiber reinforced adhesives provide significant improvement in shear stresses. These studies reveal that additives strengthen the interfacial interactions between the polymer matrix and the substrate. Boron compounds are attractive candidates due to their high thermal conductivity, oxidation resistance and capacity to form strong chemical bonds with metal surfaces. Boric acid (H_3BO_3) is a compound that can form boron-oxygen networks by dehydration during heat treatment and acts as a bridge between polymer chains and metal surfaces. However, the effect of boric acid on adhesive performance as a function of heat treatment temperature has not yet been systematically investigated. Furthermore, the combination of this compound with copolymers synthesized by free radical polymerization technique is limited in the literature. In this study, optimized polymer materials for industrial applications were synthesized. The detailed analysis of the obtained findings on the adhesion mechanisms and thermomechanical behavior of metal-metal interfaces will provide an important reference source for multidisciplinary research in this field.

2.MATERIAL AND METHOD

2.1 Synthesis of poly(glycidyl methacrylate-co-methyl methacrylate) copolymer

Azobisisobutyronitrile (AIBN) (0.044 g), glycidyl methacrylate (1.100 g, 7.74 mmol) (Figure 1) and methylmethacrylate (3.099 g, 30.95 mmol) were dissolved in 10 mL dry DMF solvent at room temperature under argon atmosphere in a 50 mL two-necked round bottom flask containing an oval magnetic stirrer (P_0). The reaction flask was immersed in an oil bath at 70 °C and the reaction mixture was stirred until a viscous solution was obtained (approximately two hours). The reaction mixture was cooled to -20 °C and precipitated in 200 mL cold methanol. The copolymers obtained at different feed ratios were isolated by filtration through a sintered G4 filter and dried at room temperature under reduced pressure to constant mass (Figure 2). The other copolymers (**P1, P2 and P3**) were prepared through the same method with mPEGMA/MMA feed ratios of 1/1, 2/1 and 4/1, respectively

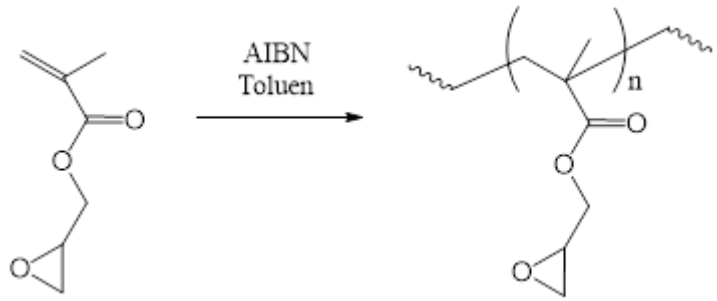


Figure 1. Synthesis of poly(GMA) polymers

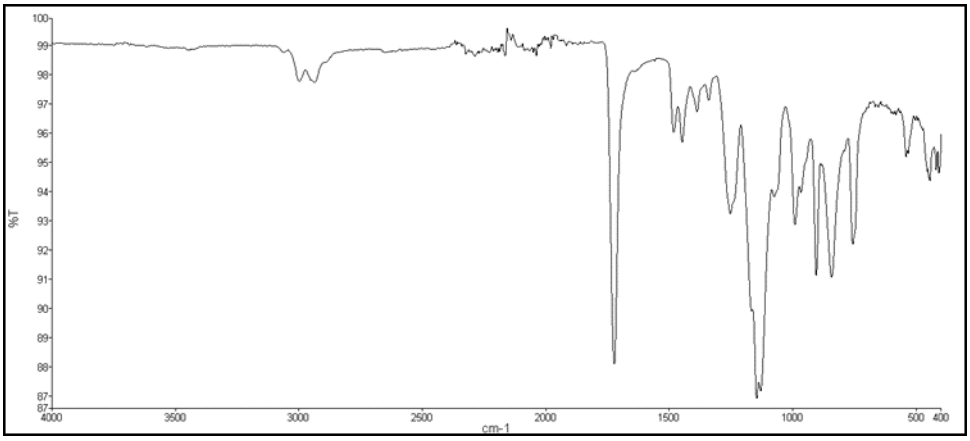


Figure 2. FTIR spectrum of PGMA

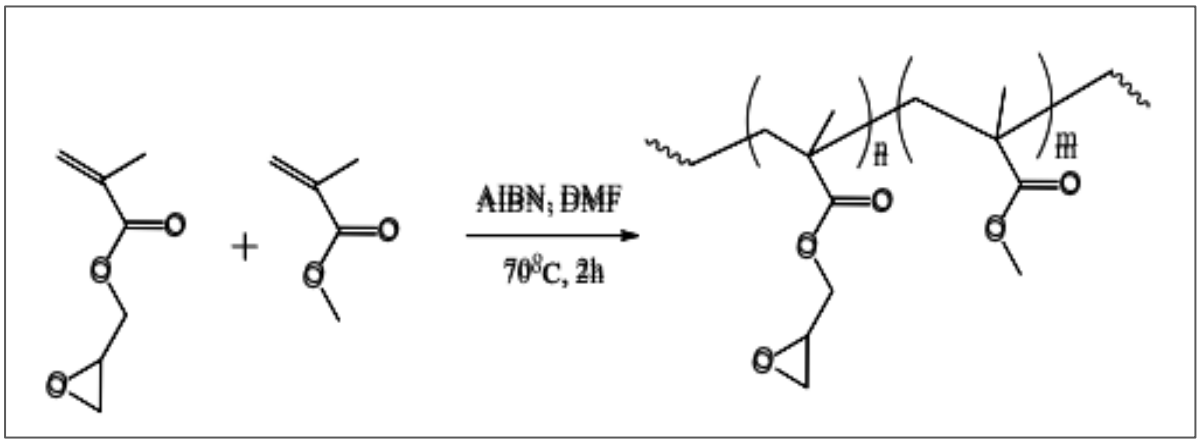


Figure 3. Synthesis of poly(GMA-co-MMA) copolymers (PS-1 PS-3)

2.2 Synthesis of poly(glycidyl methacrylate-co-methyl methacrylate) copolymer based composite

A series of solid samples were prepared by heat treatment of boric acid at different temperatures. The prepared samples were mixed with the synthesized polymers and the optimum mixing ratio was determined. Suitable composite blends were obtained considering this ratio.

2.3 Investigation of adhesion performance of poly(glycidyl methacrylate-co-methyl methacrylate) composites

The prepared polymer composite adhesives were dissolved in a suitable solvent and applied to the aluminum surface with a thickness of 0.2 mm. The two glued metals were cured at 120 °C at 5 MPa. The tensile strengths of the cooled samples were determined

2.4 Curing (Crosslinking) Process

1g of p(GMA-MMA) was dissolved in 10 mL of THF. Since diaminodiphenylmethane (DADFM), the cross-linking agent, contains two amine groups, its solution was prepared by using 0.45 times the amount of polymer(Fig. 4). This solution was applied to the prepared metal surfaces to form a 0.2 mm thick layer, which was left to dry overnight. Following this, the samples were cured for one hour at 120 °C under 6.5 MPa pressure and allowed to reach thermal equilibrium at room temperature (Figure 5). The mechanical properties of the samples, now ready for tensile testing, were evaluated using a compression and tensile testing machine.

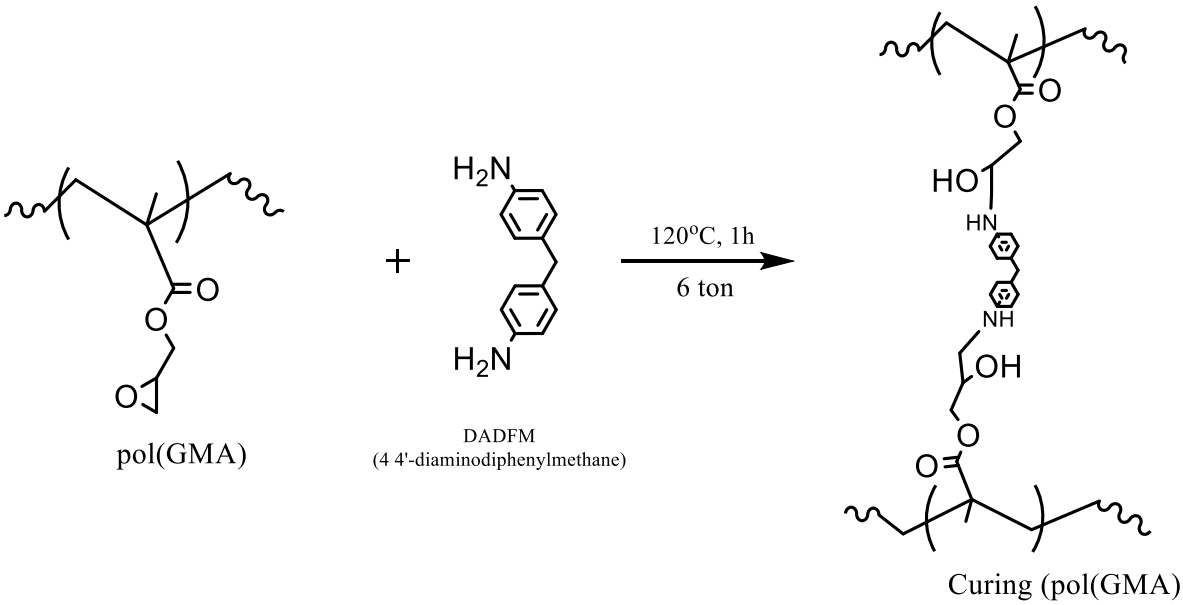


Figure 4. Epoxy ring/DADFM crosslinking

2.5 Adhesive Applications of P(GMA-MMA)

1g of PGMA was dissolved in 10 mL of methyl ethyl ketone (MEK) in a 50 mL round-bottom flask, and 0.45 moles of 4,4'-diaminodiphenylmethane (DADFM) cross-linking agent were added for each mole of epoxy group. The mixture was stirred with a magnetic stirrer until a homogeneous solution was achieved. This solution was then applied to the surfaces of 2.56.51 cm steel blocks using a dropper to form a 0.2 mm thick film. The samples were left to dry at room temperature for one day. Following drying, they were cured for one hour at 120 °C under 6.5 MPa pressure and then kept at room temperature until thermal equilibrium was reached. The mechanical properties of the samples, now ready for tensile testing, were assessed using a compression and tensile testing machine.

Figure 5. Application of the adhesive to metal surfaces (right and left) and hot press equipment where the curing process is performed (middle).

3. Results and Discussion

3.1 Mechanical Tests of the Obtained Single-Acting Adhesive Joints

Mechanical testing of the single-acting adhesive joints was conducted using a tensile compression test (Figure 5). The objective of the tensile test is to determine the elastic and plastic behavior of materials under static loads. Based on this, the aim is to optimize the mechanical properties and bonding parameters of the material. The tensile tests were carried out on three different samples prepared with PGMA using a tensile compression machine with a capacity of 250 kN. The damages occurring on the surface as a result of the tensile test were examined using a scanning electron microscope (SEM) (Figure 6). As shown in the SEM images, the polymeric adhesive exhibited both cohesive and adhesive failure due to the applied force during the tensile-compression test.

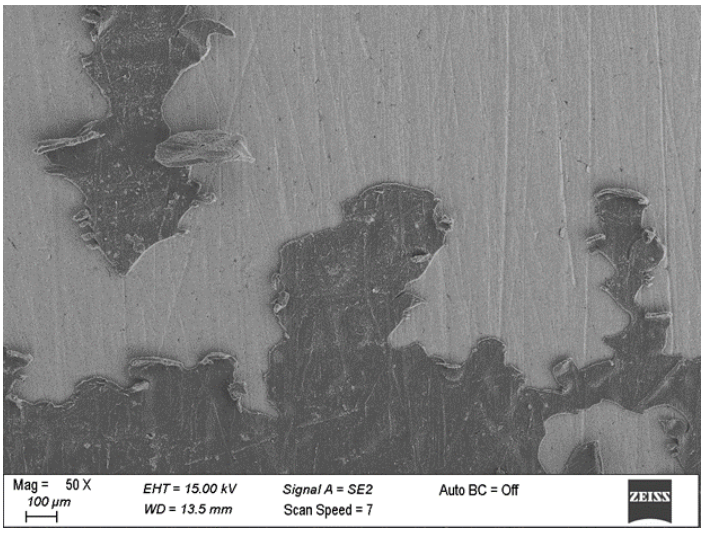


Figure 6. SEM images of P(GMA-MMA)/DADFM cross-linked polymer and magnetite particles

Shear strength/displacement curves of the thermally cured adhesive joints (denoted as P0-P3) are given in Figure 7. It was observed that the feed ratio of the polymer play significant role in the shear strength of the cured sample. Maximum strength was obtained at the feed ratios of 1/1.

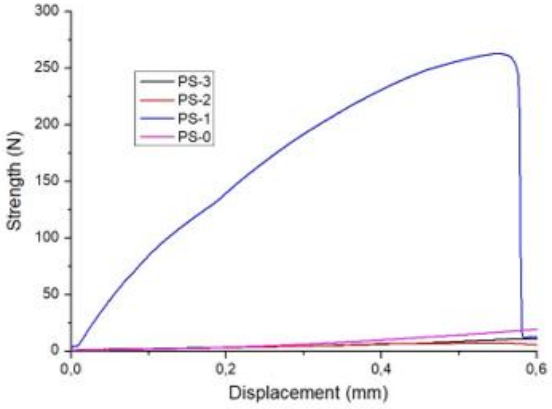
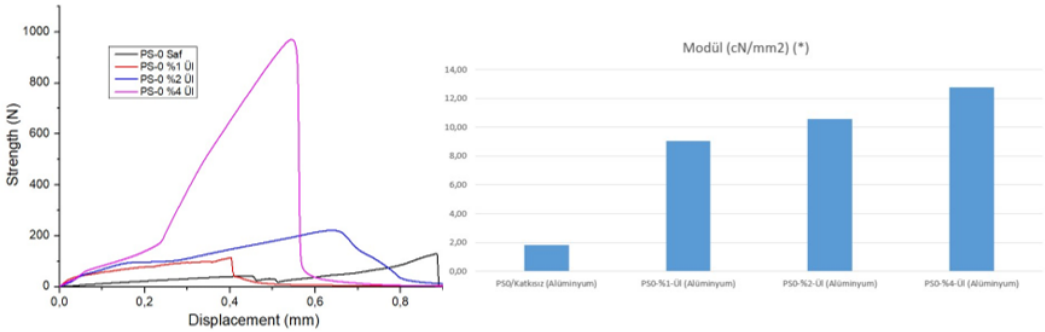


Figure 7. Strength/Displacement curves of the polymers.

The effect of heat treated boric acid on the strength development of the cured samples are given in Figs. 7-9. It was observed that the addition of heat treated boric acid to polymer matrix significantly effect the strength development of adhesive. The strength value of the sample with additive (1%) is around 1200 N that is higher than all others.



Figüre 8. Strength/Displacement curves of the polymers (PS0).

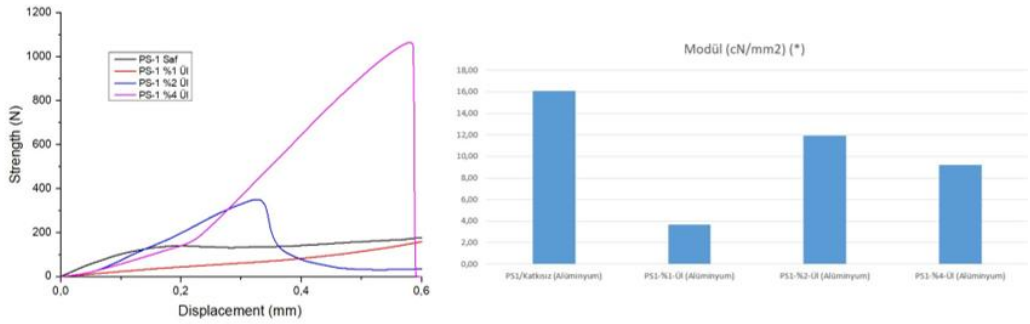


Figure 9. Strength/Displacement curves of the polymers,PS-1 (% 1,2,4 Ulexite) composite polymers on aluminum blocks

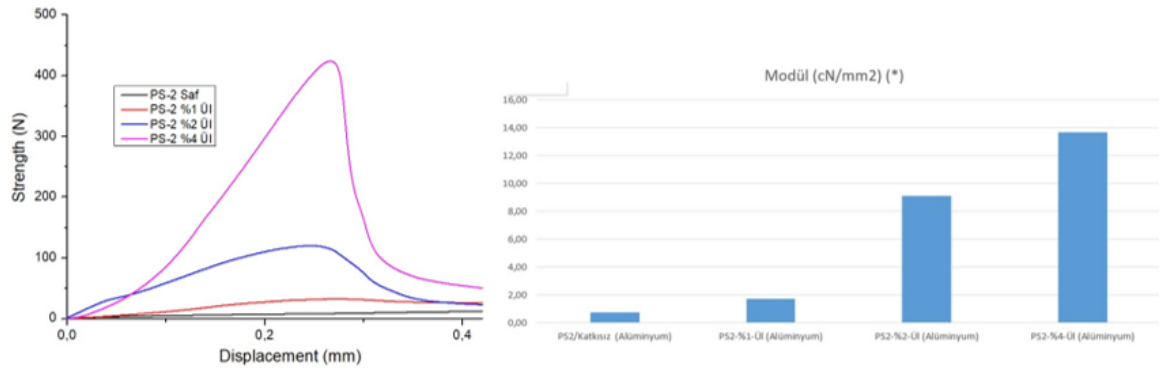


Figure 10. Strength/Displacement curves of the polymers of PS-2 (% 1,2,4 Ulexite) composite polymers on aluminum blocks

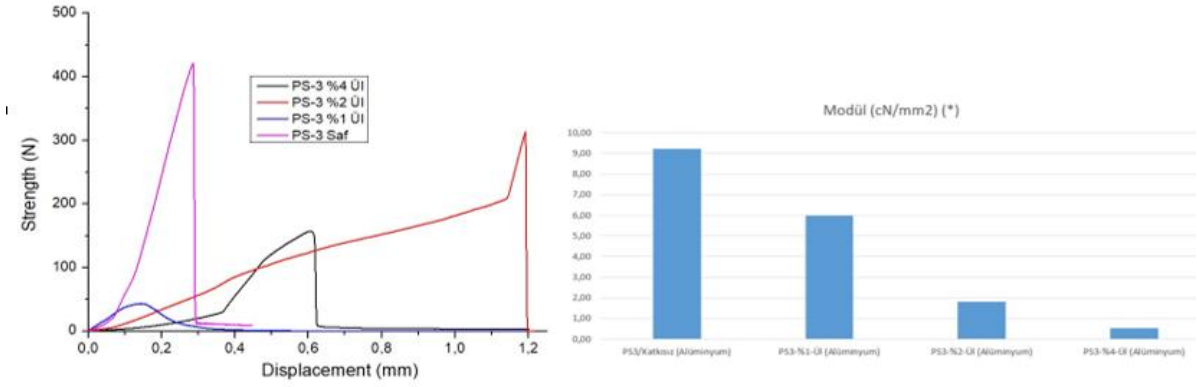


Figure 11. Strength/Displacement curves of the polymers of PS-3 (% 1,2,4 Ulexite) composite polymers on aluminum blocks

4. CONCLUSION

In this study, the adhesive beheaviors of copolymer, and copolymer composite materials have been investigated in deteails. The results showed that the inclusion of the heat treated boric acid significantly increased shear strength of the cured samples.

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KALSİNE EDİLMİŞ TİNKAL KATKILI POLİMER KOMPOZİT YAPIŞTIRICILARIN SENTEZİ VE YAPIŞMA PERFORMANSLARININ ARAŞTIRILMASI

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ÖZET
Günümüzde bağlantı elemanlarını birleştirmek için tercih edilen metotlar arasında mekanik ve kimyasal teknikler önemli bir rol oynamaktadır. Özellikle yapıştırma yöntemi, bir araya getirilmesi gereken iki veya daha fazla malzeme için sunduğu avantajlar dolayısıyla sanayide en yaygın kullanılan yöntemlerden biri haline gelmiştir. Bu proje, yenilikçi polimer bazlı materyaller ve kompozit maddelerin sentezi aracılığıyla, metal-metal bağlantı elemanlarının birleştirilmesinde kullanılacak yüksek verimli yapıştırıcıların geliştirilmesini hedeflemektedir. Yapıştırma yönteminin sağladığı avantajlar arasında uygulanabilirliğin kolay olması, geniş malzeme uyumluluğu, farklı kalınlıktaki parçalar için uygunluğu ve galvanik korozyon riskinin ortadan kaldırılması yer almaktadır. Proje kapsamında, polimerik kompozit yapıştırıcılara metal oksit mikro partikülleri eklenerek mekanik ve termal dayanımın artırılması hedeflenmektedir. Elde edilen yapıştırıcıların performansı, ASTM D1002 standartlarına göre gerçekleştirilecek mekanik testlerle değerlendirilip ve metal-metal yapıştırma bağlantıları için optimum birleştirme koşulları belirlenmiştir. Bu çalışmanın öncelikli amaçlarından biri, yüksek katma değerli yapıştırıcı ürünlerin yerli üretimini artırmak ve böylelikle ülkenin ekonomisine katkıda bulunmaktır. Proje, malzeme mühendisliği sahasında yenilikçi çözümler geliştirerek, sürdürülebilir ve rekabetçi bir sanayi ortamı oluşturulmasına katkı sağlayacaktır. Bu çalışmada, glisidil metakrilat (GMA) monomerinden poliglisidil metakrilat (PGMA) sentezlenmiştir. Sentezlenen PGMA'ya her bir epoksi grubuna karşılık belirli oranlarda 4,4'-diaminodifenilmetan (MDA) eklenerek çapraz bağlanma sağlanacak ve farklı oranlarda kalsine tinkal eklenerek kompozit yapıştırıcılar hazırlanmıştır. Hazırlanan çözeltiler çelik metal bloklara uygulanarak, numuneler oda sıcaklığında kurutulduktan sonra belirli bir sıcaklıkta ve basınç altında kürleme işlemi gerçekleştirilmiştir. ASTM D1002 standardına uygun olarak, metal bloklardan oluşturulan tek tesirli bindirme bağlantıları üzerinde çekme testleri yapılarak ve kalsine tinkalin mekanik mukavemete etkisi değerlendirilmiştir. Elde edilen sonuçlarla, kompozit yapıştırıcıların mekanik performansı analiz edilerek uygulamalarındaki potansiyel kullanımı değerlendirilmiştir.
Anahtar Kelimeler: Polimerik Kompozitler, Epoksi Matrisli Yapıştırıcılar, Kopma Mukavemeti, Bağlantı Elemanları

INVESTIGATION OF THE ADHESION PERFORMANCE OF COMPOSITE ADHESIVES OBTAINED BY ADDING CALCINED TINCAL TO POLYMERIC EPOXY ADHESIVES

ABSTRACT

In today's world, mechanical and chemical techniques play an important role among the methods preferred for joining fastening elements. Especially the adhesive bonding method has become one of the most commonly used techniques in the industry due to the advantages it offers for joining two or more materials. This project aims to develop high-performance adhesives to be used in metal-metal fastener bonding through the synthesis of innovative polymer-based materials and composite substances. Among the advantages of the adhesive bonding method are ease of application, compatibility with a wide range of materials, suitability for different thicknesses of parts, and the elimination of galvanic corrosion risk. In this project, by adding metal oxide microparticles to polymer composite adhesives, the goal is to enhance mechanical and thermal durability. The performance of the obtained adhesives will be evaluated through mechanical tests conducted according to ASTM D1002 standards, and optimum bonding conditions for metal-metal adhesive joints will be determined. One of the primary objectives of this study is to increase the domestic production of high-value-added adhesive products, thus contributing to the country's economy. The project will contribute to the development of innovative solutions in the field of materials engineering, helping to create a sustainable and competitive industrial environment. In this study, glycidyl methacrylate (GMA) monomer was synthesized into polygl glycidyl methacrylate (PGMA). Specific amounts of 4,4'-diaminodiphenylmethane (MDA) were added to the synthesized PGMA for crosslinking with each epoxy group, and composite adhesives were prepared by adding different amounts of calcined tincal. The prepared solutions were applied to steel metal blocks, and after drying the samples at room temperature, curing was performed at a specific temperature and pressure. According to ASTM D1002 standards, tensile tests were conducted on single-lap joints created from metal blocks, and the effect of calcined tincal on mechanical strength was evaluated. With the obtained results, the mechanical performance of the composite adhesives was analyzed, and their potential use in applications was assessed.

Keywords: Polymeric Composites, Epoxy Matrix Adhesives, Tensile Strength, Fasteners

1. GİRİŞ

Polimerler, çok sayıda tekrarlayan birimlerin (monomerlerin) bir araya gelmesiyle oluşan, büyük moleküllü ve zincir yapılı organik bileşiklerdir. Yunanca kökenli "poly" (çok) ve "meros" (birim) kelimelerinden türeyen "polimer" terimi, bu yapıların temel doğasını tanımlar (Mooss ve Athawale, 2016). Polimerler, hem doğada bulunan biyolojik moleküller (selüloz, proteinler, doğal kauçuk gibi) hem de sentetik olarak laboratuvar ortamında üretilen plastikler, polietilen, naylon gibi malzemeler şeklinde geniş bir yelpazeye yayılır (Khaw vd., 2023). Bu yapılar; hafiflik, kimyasal direnç, esneklik, işlenebilirlik ve düşük maliyet gibi özellikleriyle günlük yaşamda ve endüstriyel uygulamalarda yaygın şekilde kullanılmaktadır (Feng ve Zhu, 2019).

Polimer malzemelerin en önemli kullanım alanlarından biri de yapıştırıcı teknolojileridir. Geleneksel mekanik bağlantı elemanlarına (vida, perçin, kaynak) alternatif olarak kullanılan yapıştırıcılar, özellikle hafiflik, estetik görünüm, titreşim sönümleme ve homojen yük dağılımı gibi avantajları sayesinde başta otomotiv, havacılık, elektronik ve inşaat olmak üzere pek çok sektörde tercih edilmektedir (Izzah Md. Fadilah vd., 2022). ASTM standartlarına göre yapıştırıcı, iki yüzeyi yüzey temasıyla birbirine bağlayan ve ayırmaya karşı direnç gösteren bir madde olarak tanımlanır (Erova, 2023). Polimer bazlı yapıştırıcılar; termoplastik (örneğin PVA), termoset (örneğin epoksi) ve elastomerik (örneğin silikon) yapıda olabilir. Bu sınıflandırma, yapıştırıcının kürleşme şekli, esneklik düzeyi ve uygulama alanları üzerinde doğrudan etkilidir (Kinloch, 2010).

Bu bağlamda epoksi yapıştırıcılar, polimerik yapıştırıcılar arasında özellikle öne çıkan bir türdür. Epoksi yapıştırıcılar; epoksi reçinesi ve sertleştirici (kür edici ajan) olmak üzere iki ana bileşenden oluşur. Bu iki bileşenin kimyasal reaksiyonu sonucunda çapraz bağlı, termoset bir yapı oluşur. Bu yapı yüksek mekanik mukavemet, ısıl direnç ve kimyasal stabilite sağlar (Aydın, Solmaz ve Turgut, 2011). Epoksi sistemler; farklı yüzeylere iyi yapışma, çevresel faktörlere karşı direnç ve geniş sıcaklık aralığında çalışma kabiliyeti gibi üstün özelliklere sahiptir. Bununla birlikte, epoksi yapıştırıcıların mekanik performanslarını daha da iyileştirmek amacıyla çeşitli katkı maddeleri ile modifikasyon çalışmaları yapılmaktadır. Bu kapsamda, nano parçacıklar (örneğin karbon nanotüpler, SiO_2, Al_2O_3), elastomerik fazlar veya kil bazlı katkılar ile yapılan takviyeler sayesinde yapışma mukavemeti, kırılma tokluğu ve ısıya dayanıklılık gibi özelliklerde kayda değer artışlar gözlenmiştir (Khoee ve Hassani, 2010; Jiang vd., 2017; Gerson vd., 2010).

Yapıştırıcı performansını artırma çabaları sadece polimer matris modifikasyonları ile sınırlı değildir; aynı zamanda dolgu maddesi olarak kullanılan katkıların da etkileri önemli bir araştırma konusudur. Bu noktada, ülkemizin stratejik maden kaynaklarından biri olan bor mineralleri, özellikle de tinkal (sodyum borat), dikkat çekmektedir. Türkiye, dünya bor rezervlerinin yaklaşık %73'üne sahiptir ve bu kaynaklar özellikle cam, seramik, deterjan, tarım ve kimya sektörlerinde yaygın olarak kullanılmaktadır. Tinkal, genellikle Eskişehir-Kırka bölgesinde çıkarılan, renksiz ya da hafif renkli, düşük sertlikte ve özgül ağırlıkta bir mineraldir. Yapısındaki bor oksit (B_2O_3) içeriği, bu minerali ısıl işlem sonrası yüksek performanslı katkı maddesi olarak kullanmaya elverişli hale getirmektedir (Aksoy, 2023; Öztürk, n.d.).

Bor minerallerinin kompozit sistemlerde dolgu maddesi olarak kullanılması; malzemenin termal kararlılığı, mekanik dayanımı, alev geciktiriciliği ve kimyasal direnç gibi özelliklerini olumlu yönde etkileyebilir. Özellikle epoksi bazlı yapıştırıcılarda bor katkısının kullanımı ile daha dayanıklı, çevresel etkilerden daha az etkilenen, uzun ömürlü ve mekanik olarak üstün yapıştırıcı sistemler elde edilmesi mümkündür. Bu kapsamda yapılan bazı çalışmalar, bor katkılı sistemlerin yüzey enerjisini değiştirdiğini, kürleşme davranışını etkilediğini ve yapışma performansını artırdığını göstermektedir.

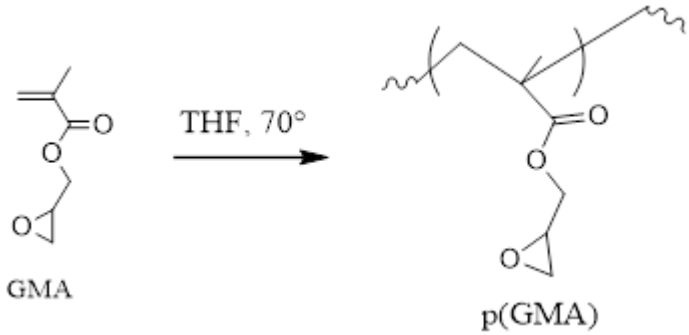
Bu çalışmada, bor minerallerinden biri olan **kalsine tincal**, epoksi yapıştırıcı sistemine dolgu maddesi olarak ilave edilerek, epoksi esaslı kompozit yapıştırıcının **alüminyum-alüminyum ve çelik-çelik ara yüzeyindeki yapışma performansı** araştırılmıştır. Böylelikle, hem yerli ve ekonomik bir dolgu maddesinin yapıştırıcı sistemine entegrasyonu hem de sistemin mekanik ve ısıl özelliklerindeki değişimlerin ortaya konulması amaçlanmıştır.

Bu çalışmanın sonucunda, yerli ve stratejik bir maden olan tinkalin yüksek katma değerli bir ürün olarak ileri teknoloji malzemelerde kullanılması yönünde katkı sağlanması hedeflenmektedir. Aynı zamanda, bor katkılı polimer kompozit yapıştırıcıların geliştirilmesi ile çevresel faktörlere karşı daha dayanıklı ve yüksek mukavemetli yapışma sistemleri elde edilmesi amaçlanmaktadır. Bu çalışma hem ülkemizin bor kaynaklarının değerlendirilmesi hem de yapıştırıcı teknolojilerinde yenilikçi malzemelerin geliştirilmesi açısından önemli bir yere sahiptir.

2. MATERYAL VE METOD

2.1 Polimer Sentezi

Azobisizobütironitril (AIBN) (0,0335 g) ve glisidil metakrilat (2,90 g, 3,85 mL) oval manyetik karıştırıcı içeren 50 mL hacimli iki boyunlu yuvarlak dipli balonda argon atmosferinde 5 mL kuru toluen çözücüsünde oda sıcaklığında çözüldü. Reaksiyon balonu 65 °C' deki yağ banyosuna daldırıldı ve reaksiyon karışımı üç saat karıştırıldı. Reaksiyon -20 °C'de soğutularak sonlandırıldıktan sonra 5 mL diklorometan (DCM) çözücüsü eklenerek çözüldü ve 200 mL soğuk metanolde çöktürüldü. p(GMA), sinterli G4 filtrede süzülerek izole edildi ve oda sıcaklığında indirgenmiş basınçta sabit kütleye ulaşıncaya kadar bekletilerek kurutudu (Şekil 1). P(GMA)'nın yapısı FT-IR spektroskopisi analizinden elde edilen veriler ile aydınlatılmıştır.



Şekil 1. Poli(GMA) polimerlerinin sentezi

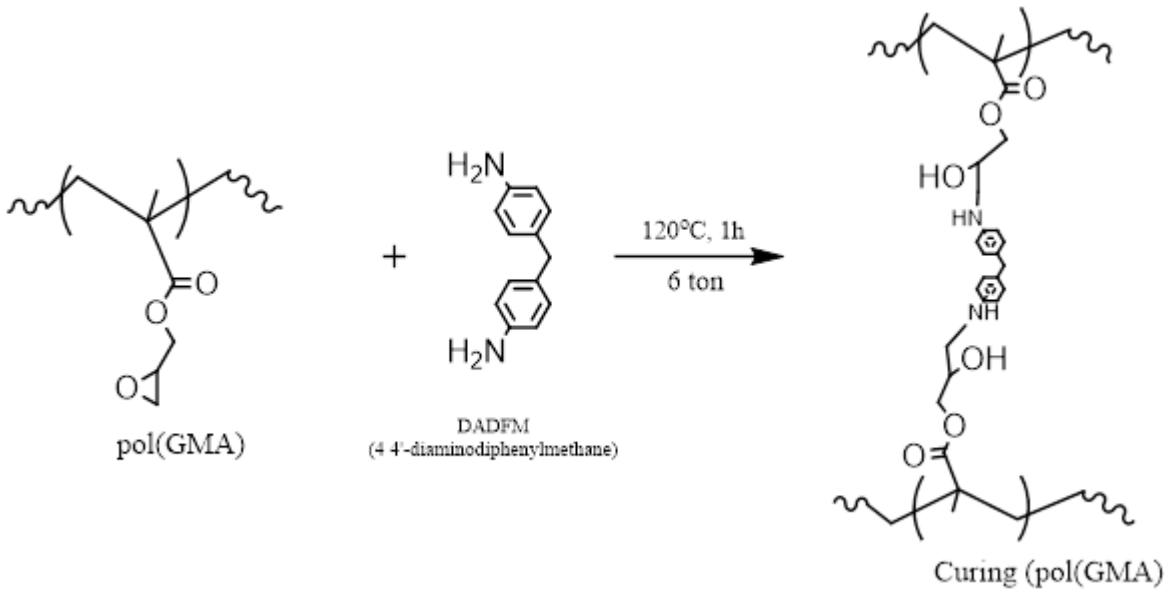
2.1 p(GMA)'nın Kompozit Formunun Hazırlanması

1g p(GMA) 25 ml yuvarlak dipli balonda 10 mL metil etil keton (MEK) içerisinde çözülecek ve üzerine her bir molepoksi grubuna karşı 0,45 mol 4 4'-methylenedianiline çapraz bağlayıcı ajan (kürleyici) eklenerek manyetik karıştırıcıda karıştırıldı. Daha sonra polimerik çözeltiye polimerin mol kütlesinin %1-2-4 oranında kalsine tinkal eklenerek dispers bir çözelti elde edilecek ve alüminyum bloklar üzerine uygulandı. 24 saat oda sıcaklığında kurumaya bırakıldıktan sonra sıcak pres makinesinde 120°C'de altı ton basınç altında kürleme işlemi gerçekleştirildi. Yapıştırılan bloklar termal dengeye geldiğinde basma ve çekme testi cihazı ile mekanik özellikleri incelenmiştir.

2.2 Kürleme (Çapraz bağlanma) İşlemi

P(GMA) polimerinden 1 gram, 5 mL tetrahidrofuran (THF) içerisinde çözündürülmüştür. Çapraz bağlayıcı ajan olarak tercih edilen ve iki amin grubuna sahip olan

diaminodifenilmetan (DADFM), polimerin kütlesinin %45'i oranında kullanılarak çözeltisi hazırlanmıştır (Şekil 2). Hazırlanan bu karışım, metal yüzeylere yaklaşık 0,2 mm kalınlığında uygulanmış ve numuneler oda sıcaklığında bir gece boyunca kurutulmuştur. Takiben, numunelere 120 °C sıcaklık ve 6,5 MPa basınç altında bir saat kürleme işlemi uygulanmıştır. Kürlemenin ardından, sistem oda sıcaklığında termal dengeye ulaşana dek bekletilmiştir (Şekil 2). Mekanik testler öncesinde hazırlanan numunelerin çekme özellikleri, basma ve çekme test cihazları yardımıyla değerlendirilmiştir.



Şekil 2. Epoksi halkasının çapraz bağlanması

2.3 P(GMA)'nın Yapıştırıcı Uygulamaları

1g PGMA 50 ml yuvarlak dipli balonda 10 mL metil etil keton (MEK) içerisinde çözündü ve üzerine her bir mol epoksi grubuna karşı 0,45 mol 4,4′-diaminodifenilmetan (DADFM) çapraz bağlayıcı ajan eklenerek manyetik karıştırıcıda homojen bir çözelti elde edilinceye kadar karıştırıldı. 2,5*6,5*1 cm çelik bloklar üzerine Şekil 3'te görüldüğü gibi damlalıkla damlatılarak 0,2 mm film kalınlığında olacak şekilde yüzeylere uygulandı ve bir gün oda sıcaklığında kurumaya bırakıldı. Daha sonra 120 °C'de 6,5 MPa basınç altında bir saat kürleme yapıldı ve oda sıcaklığında termal dengeye gelene kadar bekletildi. Çekme testleri için hazır hale gelen numuneler basma ve çekme testi cihazı ile mekanik özellikleri incelendi (Şekil 3).

Şekil 3. Yapıştırıcının metal yüzeylere uygulanması (solda) ve kürleme işleminin yapıldığı sıcak pres ekipmanı (sağda).

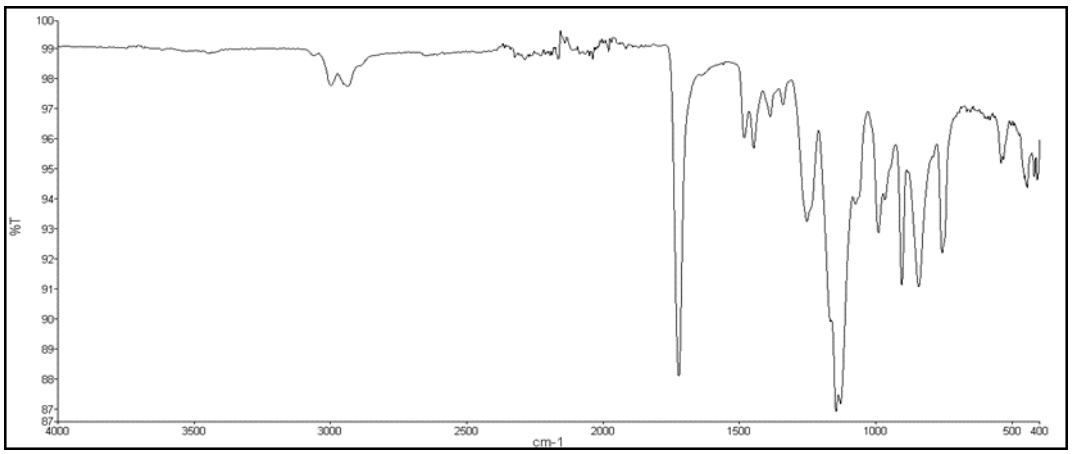
Tek tesirli yapıştırma bağlantılarının mekanik performansı, çekme-basma testleri aracılığıyla analiz edilmiştir. Çekme testlerinin temel amacı, malzemelerin statik yükleme altındaki elastik ve plastik deformasyon davranışlarının belirlenmesidir. Bu kapsamda hem yapıştırıcı malzemenin mekanik özelliklerinin hem de yapıştırma işlemi sırasında kullanılan

parametrelerin optimizasyonu hedeflenmiştir. P(GMA) kullanılarak hazırlanan üç farklı numune, alüminyum-alüminyum ve çelik-çelik plaka çiftleri üzerinde, 5 kN kapasiteli bir çekme-basma test cihazında değerlendirilmiştir.

3. Sonuçlar ve Tartışma

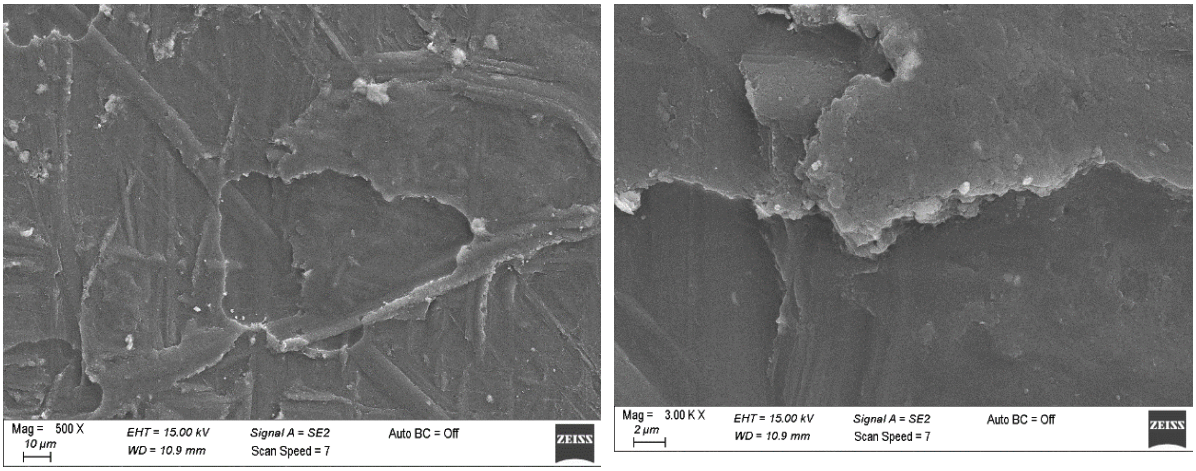
PGMA'ya ait FTIR spektrumu Şekil 4'de görülmektedir. Spektrumda 2850-2980 cm-1 arasında gözlemlenen sinyaller alifatik C-H gerilme sinyallerine aittir. Spektrumundaki PGMA polimerine ait 830-900 cm-1 arasında görülen sinyaller yapıda epoksi halkasının varlığını göstermektedir.

1731 cm-1'de gözlemlenen keskin ve güçlü pik polimerdeki ester gruplarının C=O gerilme sinyallerine aittir. Ayrıca 1640-1680 cm-1'de alken bağlarına ait sinyallerin bulunmaması polimerleşme reaksiyonunun gerçekleştiğini göstermektedir.



Şekil 4. PGMA'ya ait FTIR spektrumu

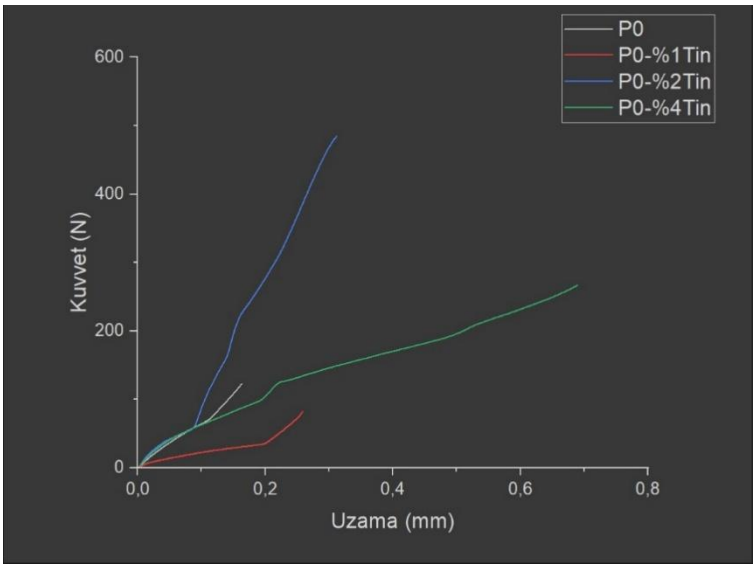
Yapışma yüzeylerine ait SEM görüntüleri Şekil 5'te görülmektedir. SEM görüntüleri, polimerik yapıştırıcının uygulanan mekanik kuvvet altında hem kohezyonel hem de adezyonel hasar davranışı sergilediğini göstermiştir.



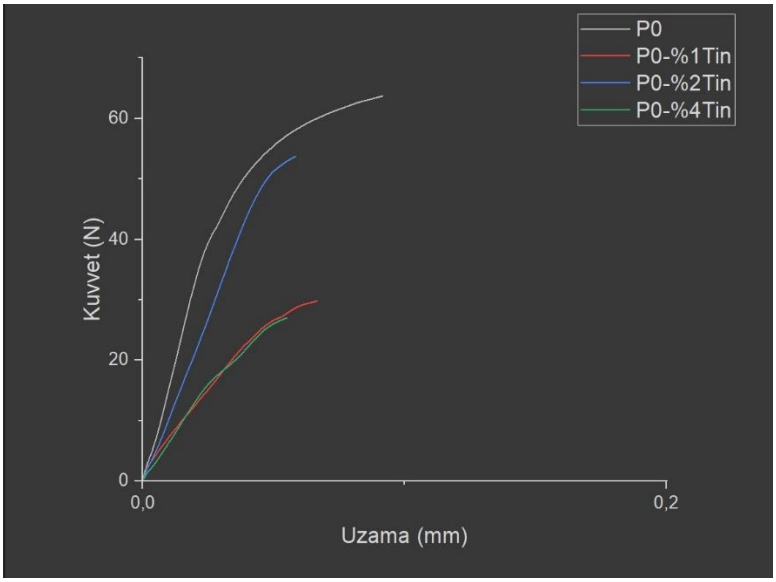
Şekil 3. P(GMA)/DADFM çapraz bağlı polimerin SEM görüntüleri

P(GMA) polimeri ve kompozitlerinin çelik-çelik ve alüminyum-alüminyum plakalardaki kopma dayanımı ve kopmadaki uzaması Şekil 6 ve Şekil 7. 'te görülmektedir. Isıl işleme tabi tutulmuş tinkal katkılı kompozit yapıştırıcıları kopma mukavemetinin önemli

oranda artığı görülmektedir. Polimer matris içinde katkı oranlarının kopma mukavemeti ile direkt olarak ilişkili olduğu görülmüştür. P(GMA) polimeri ve kompozitlerinin çelik-çelik ara yüzeyde yapışma performansları alüminyum-alüminyum ara yüzeye kıyasla çok düşük kaldığı görülmüştür. Isıl işleme tabi tutulmuş tinkal ilavesinin yapışma performansları üzerine pozitif etki yaptığı görülmektedir.



Şekil 6. P(GMA) polimeri ve kompozitlerinin alüminyum-alüminyum plakalardaki kopma dayanımı ve kopmadaki uzaması



Şekil 7. P(GMA) polimeri ve kompozitlerinin çelik-çelik plakalardaki kopma dayanımı ve kopmadaki uzaması

Yapıştırıcı uygulamalarında çelik-çelik ve alüminyum-alüminyum ara yüzeyde gerçekleşen yapışma olayları ile ilgili Young modül değerleri Tablo 1 ve Tablo 2'de verilmektedir. Tablodan da görüldüğü gibi alüminyum-alüminyum ara yüzeyde kopma mukavemetleri ve modül değerlerinin çelik-çelik ara yüzeylerle kıyaslandığında istenilen özelliklere daha yakın olduğu görülür.

Kompozit	Modül Değeri (cN/mm$^{2)}$	Kuvvet (N)	Uzama (mm)
P0	8,10	601,244	3,13845
P0-%1-Tinkal	2,83	1054,23	4,3921
P0-%2-Tinkal	12,08	1678,1	2,3508
P0-%4-Tinkal	7,82	1002,74	2,2569

Şekil 8. P0 polimeri ve kompozitlerinin alüminyum-alüminyum plakalar üzerindeki Young modül değerleri

Kompozit	Modül Değeri (cN/mm$^{2)}$	Kuvvet (N)	Uzama (mm)
P0	9,61	87,8485	2,6813
P0-%1-Tinkal	4,27	35,429	2,04795
P0-%2-Tinkal	8,07	54,4612	1,618
P0-%4-Tinkal	6,08	42,9622	2,033

Şekil 9. P0 polimeri ve kompozitlerinin çelik-çelik plakalar üzerindeki Young modül değerleri

Öneriler

Sentezlenen kopolimerler ve kompozitleri, homopolimerlere göre alüminyum blokların yapıştırılmasında arayüzey etkileşimlerini önemli ölçüde artırdığı görülmektedir. Ayrıca kopolimerlerdeki P(GMA) 'ya ait uzun zincirlerin yapıştırıcının sünekliğini artırdığı çekme testlerinden anlaşılmaktadır.

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KALSİNE EDİLMİŞ KOLEMANİT KATKILI POLİMER KOMPOZİT YAPIŞTIRICILARIN SENTEZİ VE YAPIŞMA PERFORMANSLARININ ARAŞTIRILMASI

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ÖZET

Bu projede, glisidil metakrilat kullanılarak THF çözeltisi içinde 70 °C'de polimer sentezi gerçekleştirilmiştir. Sentezlenen p(GMA) polimeri, kürleme işlemine tabi tutularak yapışma gücü artırılmış ve kolemanit katkısıyla yapıştırma performansı iyileştirilmiştir. Elde edilen ürün, tek tesirli metal-metal bağlantı elemanlarının birleştirilmesinde kullanılmak üzere geliştirilmiştir. Yapıştırılan materyallerin mekanik testleri ASTM D1002 standartlarına göre gerçekleştirilmiş ve performansları karşılaştırılmıştır. Yapıştırıcı malzemenin mekanik ve termal dayanımını artırmak amacıyla metal oksit mikro partikülleri kullanılmıştır. Farklı formülasyonlarla hazırlanan yapıştırıcıların performansları değerlendirilmiş ve optimum bileşim oranları belirlenmiştir. Ayrıca, yüzey hazırlama yöntemlerinin yapışma dayanımı üzerindeki etkileri incelenmiştir. Bu çalışma, metal-metal yapıştırma bağlantılarının optimum birleştirme koşullarını belirlemeyi ve elde edilen veriler doğrultusunda yapıştırıcıların endüstriyel ölçekli uygulamalara uygunluğunu araştırmayı amaçlamaktadır. Geliştirilen yüksek katma değerli yapıştırıcıların yerlileştirilmesi, ülke ekonomisine katkıda bulunmayı hedeflemektedir. Böylece, endüstriyel uygulamalarda daha güçlü ve dayanıklı yapıştırıcı çözümleri sunulması amaçlanmıştır.

Anahtar Kelimeler: Polimerik Kompozitler, Epoksi Matrisli Yapıştırıcılar, Kopma Mukavemeti, Bağlantı Elemanları

SYNTHESIS OF CALCINED COLEMANITE ADDITIVE POLYMER COMPOSITE ADHESIVES AND INVESTIGATION OF THEIR ADHESION PERFORMANCE

ABSTRACT

In this project, polymer synthesis was carried out using glycidyl methacrylate in THF solution at 70 °C. The synthesized p(GMA) polymer was subjected to curing process to increase the adhesion strength and the bonding performance with the addition of colemanite. The product obtained was developed to be used in the joining of single-acting metal-to-metal fasteners.

Mechanical tests of the bonded materials were carried out according to ASTM D1002 standards and their performances were compared. Metal oxide microparticles were used to increase the mechanical and thermal strength of the adhesive material. The performances of adhesives prepared with different formulations were evaluated and the optimum composition ratios were determined. In addition, the effects of surface preparation methods on adhesion strength were investigated.This study aims to determine the optimum bonding conditions of metal-metal bonding joints and to investigate the suitability of the adhesives for industrial scale applications in line with the data obtained. The localization of the developed high value-added adhesives aims to contribute to the national economy. Thus, it is aimed to provide stronger and more durable adhesive solutions in industrial applications.

Keywords: Polymeric Composites, Epoxy Matrix Adhesives, Tensile Strength, Fasteners

1. GİRİŞ

Polimerler, bir veya daha fazla atom türünün, yapısal tekrarlayan birimlerden birinin veya birkaçının eklenmesiyle belirgin bir şekilde değişmeyen bir dizi özellik sağlamak üzere birbirine bağlanmış çoklu tekrarıyla karakterize edilen moleküllerdir. "Polimer" kelimesi, Yunanca "poly" (çok) ve "mer" (parça) kelimelerinden türetilmiştir. Polimerlerin işlenme kolaylığı, mekanik davranışları, esnek yapıları ve düşük yoğunlukları, onları özellikle yapıştırıcı üretiminde ideal hale getirmektedir. Polimerik yapıştırıcılar, bu avantajları sayesinde endüstriyel uygulamalarda yaygın olarak kullanılmaktadır. Yapıştırıcılarla birleştirme, mekanik bağlantılar oluşturarak malzemelerin birbirine bağlanmasını sağlar. Diğer birleştirme yöntemlerine kıyasla (kaynak, perçin bağlantıları vb.) daha az enerji tüketimi ve daha basit işleme yöntemleri sunar (Şahmetlioğlu vd., 2007). Yapıştırıcıların fiziksel ve kimyasal özelliklerindeki gelişmeler, bu teknolojinin yaygınlığını artırmış ve uçak, otomotiv ve denizcilik gibi birçok alanda dinamik yükler altındaki kullanımını teşvik etmiştir (Şahin, 2000).

Polimerik yapıştırıcılar, özellikle epoksi reçineler hem yüksek mekanik özellikler hem de dayanıklılık açısından en çok tercih edilen materyaller arasında yer almaktadır. Epoksi reçineler, moleküler yapılarındaki epoksi gruplarından dolayı yüksek mekanik, kimyasal ve termal dayanım sergiler. Bu özellikleri, onları polimer kompozitlerde yaygın şekilde kullanılabilir hale getirmektedir. Epoksi reçinelerin üstün özellikleri arasında yüksek çekme ve darbe dayanımları, aşınmaya karşı dirençleri, yüksek sıcaklıklarda iyi performans göstermeleri, her tür yüzeye yapışabilme yetenekleri ve düşük viskoziteleri yer almaktadır (Durmuş, 2006). Bu nedenle epoksi reçineler, özellikle yapısal yapıştırıcılar olarak yaygın bir şekilde kullanılır ve yapılan bazı çalışmalar bu tür yapıştırıcıların performans artışı sağlamak için çeşitli katkı maddeleriyle güçlendirilebileceğini göstermektedir.

Örneğin, (Kumar & Patel, 2015) tarafından yapılan çalışmada, grafen takviyeli epoksi reçineler kullanılarak karbon fiber takviyeli plastik malzemelerin yapıştırılması sağlanmış ve %28'lik bir mukavemet artışı elde edilmiştir. Ayrıca, grafen takviyesi, darbe dayanımını ve yorulma ömrünü de artırmıştır. (Jiang & Ark, 2017) çalışmasında ise, nano-kil içeren epoksi reçineler kullanılarak karbon fiber ve cam elyaf takviyeli kompozit malzemeler birleştirilmiş ve yapıştırıcının mukavemeti %22 artmıştır. Nano-kil katkısının yapıştırıcı tokluğuna önemli katkılar sağladığı belirtilmiştir. Benzer şekilde, (Lee & Wong, 2019) tarafından yapılan araştırmada, %6 silika nanoparçacık içeren polimer reçine ile yapılan yapıştırma işlemi sonrasında, mukavemet testlerinde %30, diğer mekanik testlerde ise %38'lik bir iyileşme gözlemlenmiştir. Ayrıca, silika takviyesi, yapıştırıcının elastikiyet modülünü artırarak bağlantı noktalarının performansını önemli ölçüde yükseltmiştir. (Tan & Chen, 2020) tarafından yapılan bir başka çalışmada ise, %5 alümina nanoparçacığı içeren epoksi yapıştırıcılarla yapılan birleştirmeler sonucunda, mukavemetin %32 oranında arttığı ve bağlantı bölgesinin yorulma dayanımının %40'a varan iyileşmeler sağladığı gözlemlenmiştir.

Kompozit malzemeler, farklı malzeme türlerinin en iyi özelliklerini birleştirerek üstün performans gösteren yeni malzemeler oluşturur. Polimer bazlı kompozitler, yüksek mukavemet, hafiflik, termal stabilite ve aşınma direnci gibi özelliklerinden dolayı birçok endüstride yaygın olarak kullanılmaktadır. Ayrıca, kompozit malzemeler, metallerin sertliğine ve dayanıklılığına uyum sağlayabilirken, aynı zamanda hafif olma özellikleri ile önemli avantajlar sunmaktadır. Kompozitler, kalıplanabilirlikleri sayesinde istenilen şekil ve

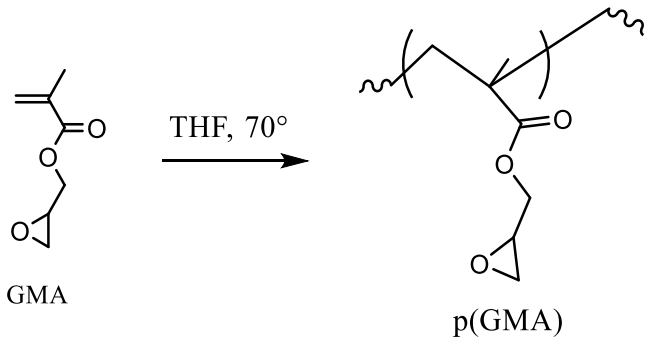
performans özelliklerine göre tasarlanabilir ve bu da onları daha uygun maliyetli ve verimli hale getirir (Bozkurt, 2014).

Türkiye, dünya bor rezervlerinin %72'sine sahip olan önemli bir ülkedir ve kolemanit mineralinin, epoksi reçinelerle birleşimi, kompozit malzemelerin mekanik ve termal özelliklerini geliştirme kapasitesine sahiptir. Kolemanit, özellikle kalsinasyon işleminden sonra polimer matrislere dahil edilerek, kompozitlerin dayanımını artırmaktadır. Bu projede, kolemanit mineralinin farklı sıcaklıklarda işlenmesiyle elde edilen epoksi polimerleri ile yapılan kompozit yapıştırıcıların, alüminyum ve çelik ara yüzeylerdeki yapışma performansları detaylı bir şekilde araştırılacaktır (Alp vd., 1995; Arıcasoy, 2006; Müdürlüğü, 2009; Sertkaya & BAYAT, 2007).

2. MATERYAL VE METOD

2.1 Polimer Sentezi

Azobisizobütironitril (AIBN) (0,0335 g) ve glisidil metakrilat (2,90 g, 3,85 mL) oval manyetik karıştırıcı içeren 50 mL hacimli iki boyunlu yuvarlak dipli balonda argon atmosferinde 5 mL kuru toluen çözücüsünde oda sıcaklığında çözüldü. Reaksiyon balonu 65 °C' deki yağ banyosuna daldırıldı ve reaksiyon karışımı üç saat karıştırıldı. Reaksiyon -20 °C'de soğutularak sonlandırıldıktan sonra 5 mL diklorometan (DCM) çözücüsü eklenerek çözüldü ve 200 mL soğuk metanolde çöktürüldü. P(GMA), sinterli G4 filtrede süzülerek izole edildi ve oda sıcaklığında indirgenmiş basınçta sabit kütleye ulaşıncaya kadar bekletilerek kurutuldu (Şekil 2.1.).



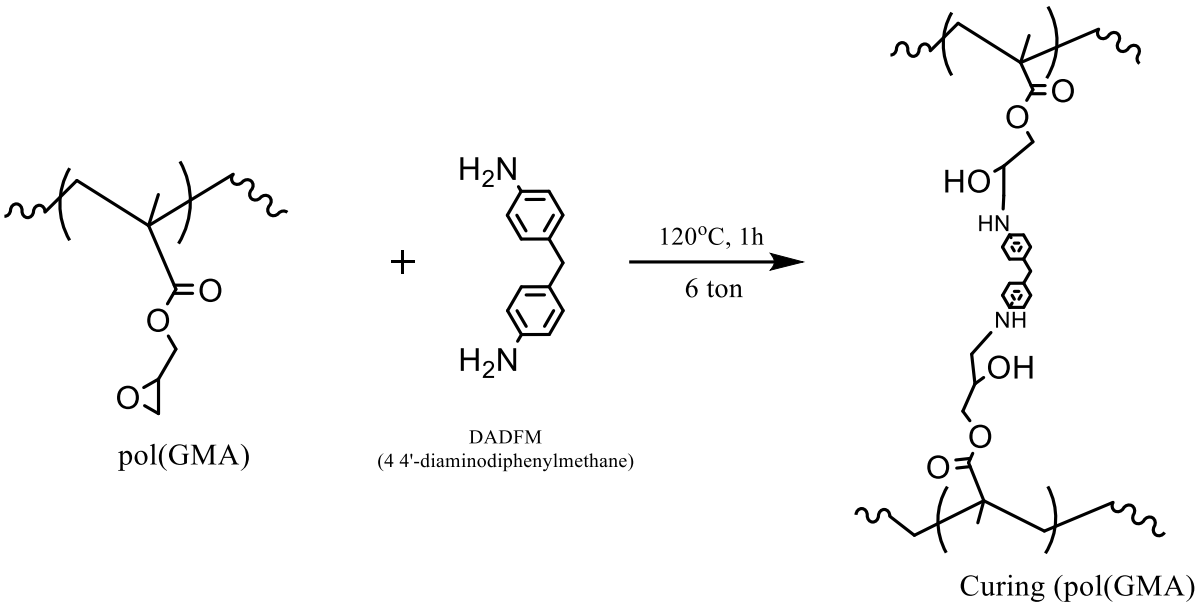
Şekil 2.1. p(GMA) polimerlerinin sentezi

2.2 P(GMA)'nın Kompozit Formunun Hazırlanması

1g p(GMA) 25 ml yuvarlak dipli balonda 10 mL metil etil keton (MEK) içerisinde çözüldü ve üzerine her bir mol epoksi grubuna karşı 0,45 mol 4 4'-methylenedianiline çapraz bağlayıcı ajan (kürleyici) eklenerek manyetik karıştırıcıda karıştırıldı. Daha sonra polimerik çözeltiye polimerin mol kütlesinin %1-2-4 oranında kalsine kolemanit eklenerek dispers bir çözelti elde edildi ve alüminyum bloklar üzerine uygulandı. 24 saat oda sıcaklığında kurumaya bırakıldıktan sonra sıcak pres makinesinde 120°C'de altı ton basınç altında kürleme işlemi gerçekleştirildi. Yapıştırılan bloklar termal dengeye geldiğinde basma ve çekme testi cihazı ile mekanik özellikleri incelendi.

2.3 Kürleme (Çapraz bağlanma) İşlemi

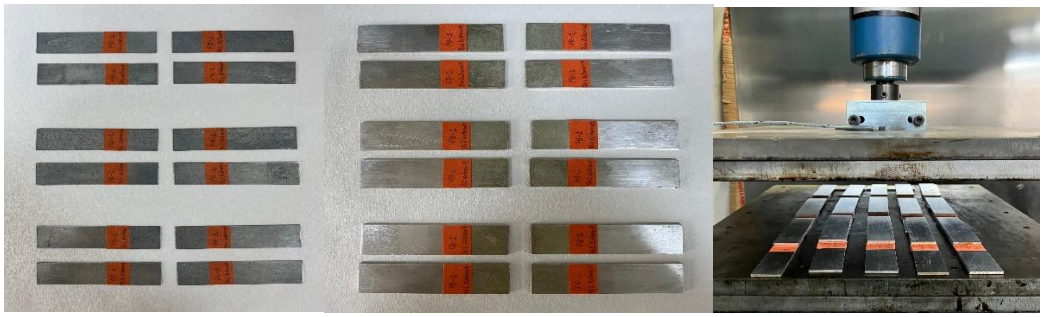
1 g p(GMA), 5 mL tetrahidrofuran (THF) içerisinde çözündürülmüştür. Çapraz bağlayıcı ajan olarak kullanılan diaminodifenilmetan (DADFM), iki amin fonksiyonel grubuna sahip olması nedeniyle, polimer miktarının %45'i oranında hesaplanarak çözeltisi hazırlanmıştır. Elde edilen bu çözelti, metal yüzeylere yaklaşık 0,2 mm kalınlığında uygulanmış ve numuneler bir gece boyunca ortam sıcaklığında kurutulmuştur. Kuruma işleminin ardından, numuneler 120 °C sıcaklık ve 6,5 MPa basınç altında bir saat kürlenmiş; ardından oda sıcaklığında termal denge sağlanıncaya kadar bekletilmiştir (Şekil 2.2). Mekanik özelliklerin değerlendirilmesi amacıyla hazırlanan numuneler, basma ve çekme test cihazları kullanılarak analiz edilmiştir.



Şekil 2.2. Epoksi halkasının çapraz bağlanması

2.4 P(GMA)'nın Yapıştırıcı Uygulamaları

1 g PGMA, 50 mL'lik yuvarlak dipli bir balon içinde 10 mL metil etil keton (MEK) içerisinde çözündü. Çözeltiye, her bir mol epoksi grubuna karşılık gelecek şekilde 0,45 mol 4,4′-diaminodifenilmetan (DADFM) çapraz bağlayıcı ajan eklendi ve manyetik karıştırıcı kullanılarak homojen hale gelene kadar karıştırıldı. Elde edilen çözelti, damlalık yardımıyla 2,5 × 6,5 × 1 cm boyutlarındaki çelik ve alüminyum bloklar üzerine uygulanarak 0,2 mm kalınlığında bir film oluşturuldu. Numuneler, oda sıcaklığında bir gün süreyle kurutulduktan sonra, 120 °C sıcaklıkta ve 6,5 MPa basınç altında bir saat boyunca kürleme işlemine tabi tutuldu. Kürleme sonrasında, numuneler oda sıcaklığında termal dengeye ulaşana kadar bekletildi. Hazırlanan numunelerin mekanik özellikleri, basma ve çekme test cihazları kullanılarak değerlendirildi.

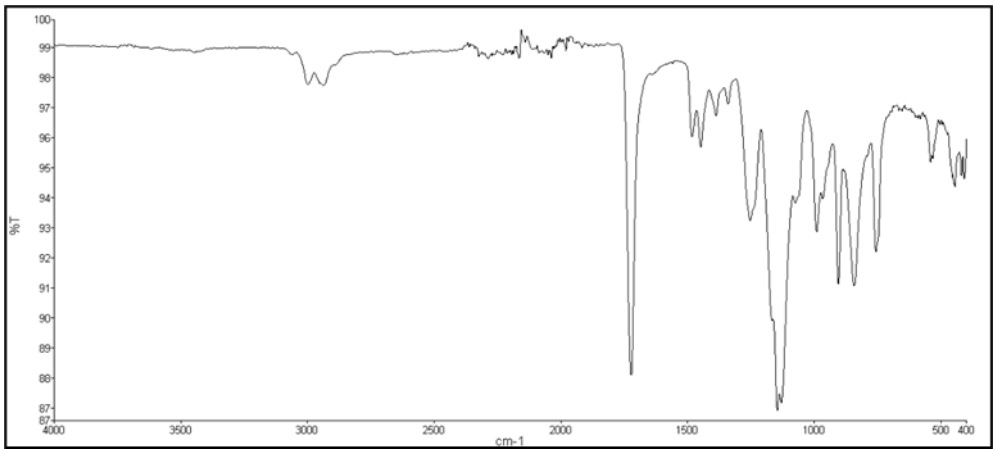


Şekil 2.3. Yapıştırıcının metal yüzeylere uygulanması (ilk fotoğraf alüminyum, ikinci fotoğraf çelik plakalar) ve kürleme işleminin yapıldığı sıcak pres ekipmanı (sağda).

Elde edilen tek tesirli yapıştırma bağlantılarının mekanik özellikleri çekme-basma testleri ile değerlendirilmiştir. Çekme testinin temel amacı, malzemelerin statik yük altındaki elastik ve plastik davranışlarının belirlenmesidir. Bu doğrultuda, hem malzemenin mekanik karakteristikleri hem de yapıştırma parametrelerinin optimizasyonu amaçlanmıştır.

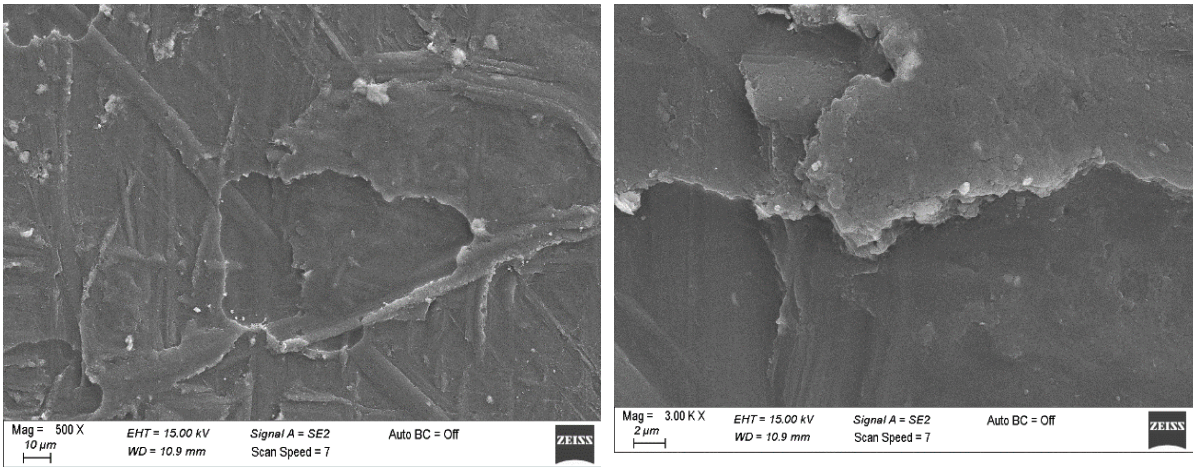
3. BULGULAR

P(GMA)'ya ait FTIR spektrumu Şekil 3.1.'de görülmektedir. Spektrumda 2850-2980 cm-1 arasında gözlemlenen sinyaller alifatik C-H gerilme sinyallerine aittir. Spektrumundaki PGMA polimerine ait 830-900 cm-1 arasında görülen sinyaller yapıda epoksi halkasının varlığını göstermektedir.
1731 cm-1'de gözlemlenen keskin ve güçlü pik polimerdeki ester gruplarının C=O gerilme sinyallerine aittir. Ayrıca 1640-1680 cm-1'de alken bağlarına ait sinyallerin bulunmaması polimerleşme reaksiyonunun gerçekleştiğini göstermektedir.



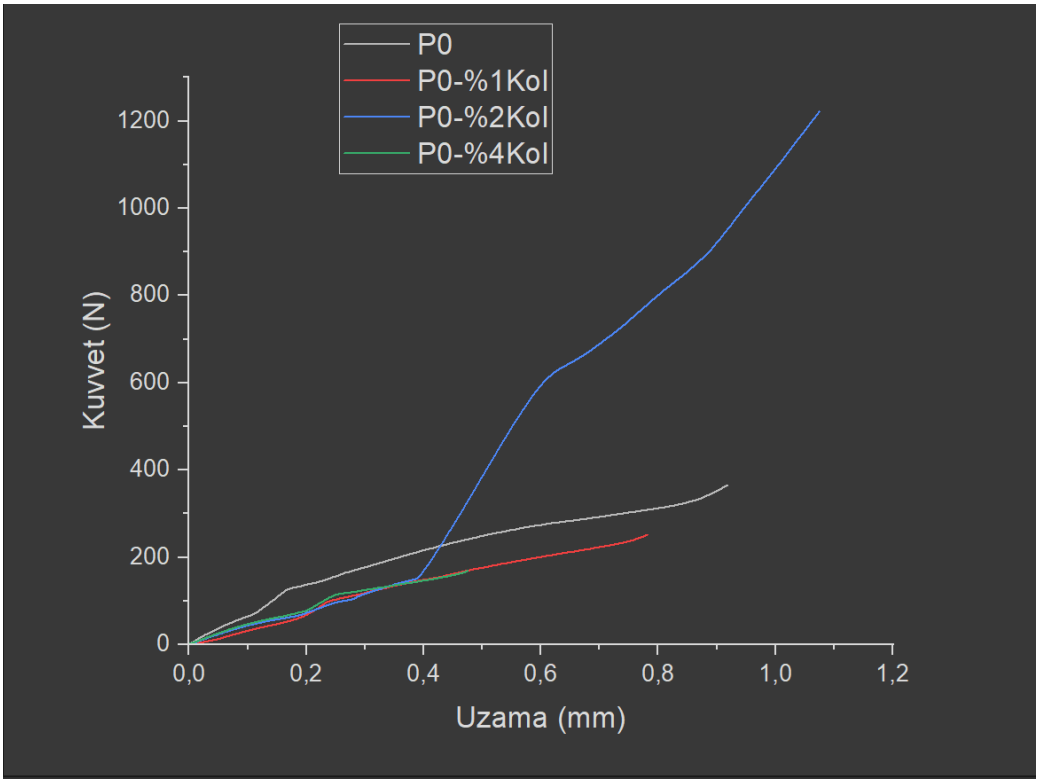
Şekil 3.1. P(GMA)'ya ait FTIR spektrumu

P(GMA) kullanılarak hazırlanan üç farklı numunenin çekme testleri, alüminyum-alüminyum ve çelik-çelik plaka çiftleri üzerinde, 5 kN kapasiteli bir çekme-basma cihazı ile gerçekleştirilmiştir. Test sonuçlarına göre, maksimum dayanım alüminyum plakalar için 1,2 kN, çelik plakalar için ise 0,065 kN olarak ölçülmüştür. Çekme testleri sonrasında yapışma yüzeylerinde meydana gelen hasarlar taramalı elektron mikroskobu (SEM) ile incelenmiş ve elde edilen görüntüler, polimerik yapıştırıcının uygulanan mekanik gerilme altında hem kohezyonel hem de adezyonel hasar türlerini gösterdiğini ortaya koymuştur (Şekil 3.2.).

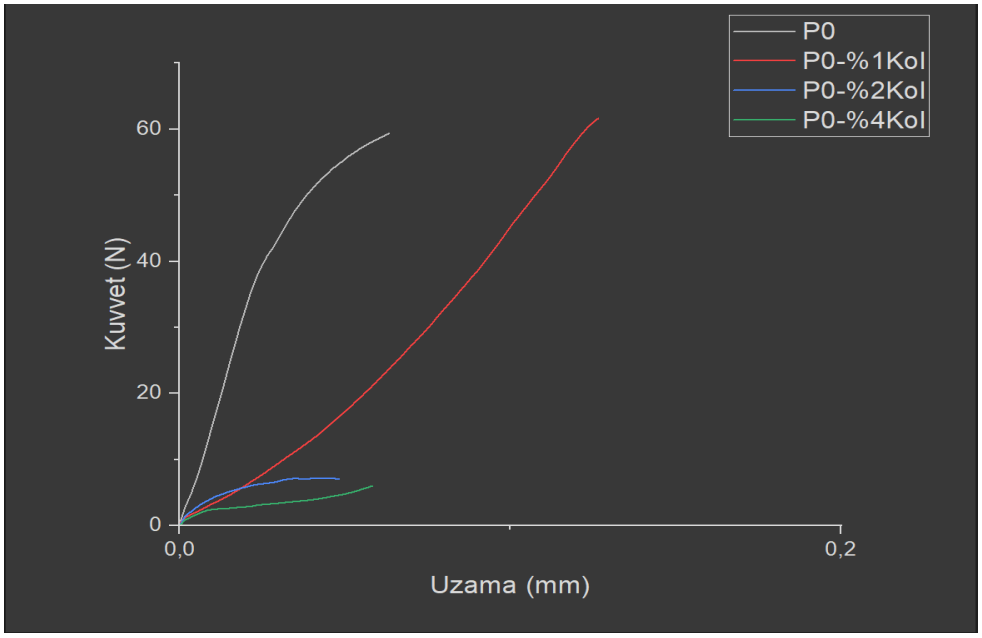


Şekil 3.2. P(GMA) çapraz bağlı polimerin SEM görüntüleri

Isıl işleme tabi tutulmuş kolemanit katkılı polimer yapıştırıcıların kopma mukavemetleri üzerine etkisi Şekil 3.3, ve 3.4 'de görülmektedir. Şekillerde görüldüğü gibi hazırlanan kompozit yapıştırıcıların yapışma performansları alüminyum-alüminyum ve çelik-çelik bağlantı elemanları için farklılık göstermektedir. Çelik-çelik ara yüzeyinde kolemanit katkılı kompozit yapıştırıcıların yapışma performansların çok düşük olduğu görülmektedir.



Şekil 3.3. P(GMA) polimeri ve kompozitlerinin alüminyum-alüminyum plakalardaki kopma dayanımı ve kopmadaki uzaması



Şekil 3.4. P(GMA) polimeri ve kompozitlerinin çelik-çelik plakalardaki kopma dayanımı ve kopmadaki uzaması

Tablo 1 ve 2'de sırasıyla alüminyum-alüminyum ve çelik-çelik plakalar üzerindeki Young modül değerleri verilmiştir. Tablolardan da görüldüğü gibi katkısız yapıştırıcıların modül değerleri her iki arayüzey için katkılı numunelere oranla daha yüksek olduğu görülmüştür. Isıl işleme tabi tutulmuş polimer kompozit yapıştırıcıların modül değerleri katkı miktarına bağlı olarak değişiklik göstermektedir. %2 kolemanit katkılı kürlenmiş örneklerin modül değeri ve uzama miktarları dikkate alındığında alüminyum-alüminyum ara yüzeylerde yapıştırıcı olarak kullanılabileceği görülmektedir.

Young Modül Değerleri – Alüminyum Plaka	
Kompozit	Modül Değeri (kN/mm²)
P0	8,1
P0-%1 Kol	4,05
P0-%2 Kol	5,36
P0-%4 Kol	5,84

Tablo 3.1. P0 polimeri ve kompozitlerinin alüminyum-alüminyum plakalar üzerindeki Young modül değerleri

Young Modül Değerleri – Çelik Plaka	
Kompozit	Modül Değeri (kN/mm²)
P0	9,61
P0-%1 Kol	7,12
P0-%2 Kol	2,11
P0-%4 Kol	2,2

Tablo 3.2. P0 polimeri ve kompozitlerinin çelik-çelik plakalar üzerindeki Young modül değerleri

4. SONUÇ

Bu çalışmada epoksi içeren yapıştırıcıların alüminyum-alüminyum ve çelik-çelik ara yüzeylerde yapışma ajanı olarak kullanılabilirliği araştırılmıştır. Polimer yapıştırıcıların yapışma performansları üzerine ısı işleme tabi tutulmuş kolemanit katkısının etkisi incelenmiştir. Kolemanit katkısının alüminyum-alüminyum ara yüzeylerde yapışma performanslarını önemli oranda artırdığı görülmüştür. Kolemanit içeren yapıştırıcıların ara yüzey uygulamalarında kullanılabilmesi için uzun dönem kararlıkları detaylı bir şekilde araştırılmalıdır.

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SYNTHESIS, CHARACTERIZATION, AND INVESTIGATION OF ADHESIVE APPLICATIONS OF EPOXY-CONTAINING POLYMERIC AND POLYMERIC COMPOSITE MATERIALS

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ABSTRACT
In this study, the synthesis and characterization of synthetic polymeric adhesives and the mechanical properties of metal-metal joints bonded with these adhesives were investigated. Adhesive technology enables the use of adhesives that show high performance under static and dynamic loads and replaces classical joining methods. The bonding process is an easy and cheap process. It easily joins very thin or thick parts and since it contains lightweight connecting elements, its strength/weight ratio is extremely high. It is used to join various materials in many sectors, especially in the automotive sector. There is no alternative to the bonding method in automobile parts where friction is high (to fix the brake pad to the composite material). In this study, Pol(GMA) polymer and pol(GMA-co-PEGMEMA) copolymers were synthesized with the free radical polymerization (SRP) method at different feed rates. In order to increase the chemical, thermal and mechanical strength of polymeric adhesives, their composites were prepared with micro-scale metal oxides (Ulexite). It has been determined that the addition of 3% by weight nanoclay to epoxy adhesives increases the impact and tensile strength of epoxy by 88% and 21% (Zhang et al., 2018). The obtained polymeric and polymeric composite adhesives were used to bond metal-metal single-action lap joints and their mechanical properties were examined according to ASTM D1002 standards. Thus, both the interface interactions of the epoxy adhesive were tried to be strengthened (reduced brittleness) and its thermal and mechanical performance were increased.
Keywords: Key words: Oxirane-containing polymers, Adhesive joint elements, Polymer adhesive composites

INTRODUCTION

Epoxide compounds and their derivatives, which are one of the fields of organic chemistry, are of great importance. They are widely used in the polymer and pharmaceutical industry, in the production of biological-physiological active substances. Among these, resins and polymers are mainly used in many areas of the industry. In developed countries, tons of epoxide resins are produced (Harper et al., 2017). Nowadays, there are many methods for combining materials. These methods are pressing, soldering, welding, bolts, rivets, bonding, etc. Adhesive bonding is a method of joining two or more materials in which a mechanical connection is created using adhesives. The bonding method has become a frequently used method due to the many advantages it provides (Waite, 2017). Glycidyl methacrylate is one of the most widely used vinyl monomers in adhesive applications (Pethrick, 2015). Various materials with different architectures have been produced via radical polymerization and ring-opening reactions of vinyl and epoxy groups, respectively (Aslan et al., 2009; Wei XinFeng et al., 2018). The high ring strain of the C-O-C ring and the presence of electrophilic partially positively charged carbon (+δC-O-+δC) centers are the main factors behind the superior reactivity of the epoxy ring (Bakhtin et al., 2020; Rafique et al., 2016). Regioselective nucleophilic ring-opening reactions of the epoxy ring have been used for functional group modifications and grafting of polymers as well as to obtain cross-linked polymeric networks (Rafique et al., 2016; Yoshimoto et al., 2009). When coupled with diamines or multi-amines, the formed structures exhibited improved adhesion to metallic surfaces (Jin et al., 2015). Different mechanisms have been proposed to explain the interaction at the interface between the adhesive and the metallic substrate, such as adsorption (physical and chemical) and electrostatic and acid-base interactions (Tian et al., 2024). The adhesive was synthesized with a biomimetic terpolymer of dopamine methacrylamide (DMA), methyl methacrylate (MMA), and poly(ethylene glycol) methyl ether methacrylate (mPEGMA) monomers (Meredith & Wilker, 2015). They varied the amounts of MMA and mPEGMA while keeping the amount of DMA constant. They concluded that the presence of the MMA monomer contributes to the rigidity of the polymer, whereas the PEG side chains of the mPEGMA monomer impart flexibility (Zaporojtchenko et al., 2005). Epoxy resins are primarily used in the automotive industry in the skirts of cars. Other areas of use include door mirrors and rear lights (Kasper et al., 2021). In this study, unique, innovative polymer materials were synthesized for use in adhesive applications. The resulting products were used for bonding metal-metal connections frequently used in the automotive industry.

MATERIAL AND METHOD

Synthesis of Poly(Glycidyl Methacrylate) (PGMA)

Azobisisobutyronitrile (AIBN) (0.0335 g) and glycidyl methacrylate (2.90 g, 3.85 mL) were dissolved in 5 mL of dry toluene solvent at room temperature under an argon atmosphere in a 50 mL two-necked round-bottom flask, equipped with an oval magnetic stirrer. The reaction flask was placed in an oil bath at 65 °C, and the reaction mixture was stirred for three hours.

After the reaction was completed by cooling the mixture to -20 °C, 5 mL of dichloromethane (DCM) was added to dissolve the product, and the mixture was then precipitated in 200 mL of cold methanol. PGMA was isolated by filtration using a sintered G4 filter and dried under reduced pressure at room temperature until a constant mass was achieved (Figure 1). The structure of the PGMA polymer was confirmed using FT-IR spectroscopy. The

FT-IR spectrum of PGMA is shown in Figure 2. The peaks observed between 2850-2980 cm^{-1} correspond to the aliphatic C-H stretching vibrations. The peaks in the range of 830-900 cm^{-1} are indicative of the epoxy ring present in the polymer structure. The sharp and strong peak at 1731 cm^{-1} is associated with the C=O stretching vibrations of the ester groups in the polymer. Furthermore, the absence of peaks around 1640-1680 cm^{-1}, which would correspond to alkene bonds, confirms that the polymerization reaction has successfully occurred.

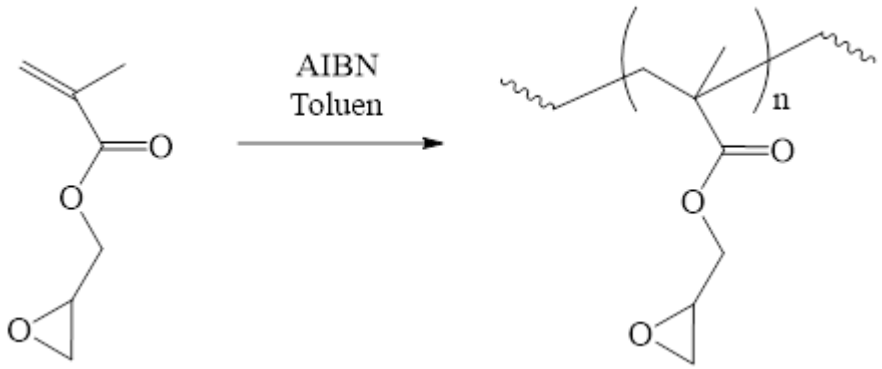


Figure 1. Synthesis of poly(GMA) polymers

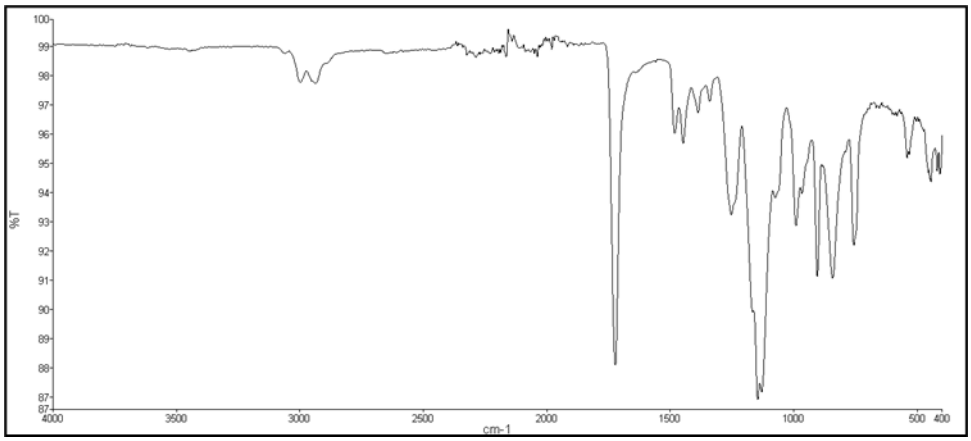


Figure 2. FTIR spectrum of PGMA

Synthesis of P1-P3 Polymers and Determination of Tensile Strength through Mechanical Strength Tests

First, PEGMEM and GMA monomers were passed through a basic alumina column to remove inhibitors. An oval magnet was placed in a 25 mL round-bottom flask, and 1.02 mL (7.03 mmol) of GMA was heated at 60°C for 20 minutes under an argon atmosphere. After heating, 34 mg of AIBN was added as an initiator, and free radical polymerization was initiated by adding 5 mL of THF. The reaction was carried out in an oil bath at 60°C with stirring at 400 rpm until completion. Upon completion of the reaction, the polymer was precipitated twice in 200 mL of cold hexane. The resulting pol(GMA) (P0) homopolymer was filtered through a sintered Gooch crucible, sealed, and dried in a vacuum oven for 24 hours. For copolymer synthesis, three different monomer feeding ratios were used. In each case, an oval magnet was placed in three separate 25 mL round-bottom flasks. In the first flask, 1.02 mL (7.7 mmol) GMA and 2.14 mL (7.7 mmol) PEGMEM were added under an argon atmosphere. In the

second flask, 1.02 mL (7.7 mmol) GMA and 4.28 mL (15.4 mmol) PEGMEM were combined. In the third flask, 1.02 mL (7.7 mmol) GMA and 8.56 mL (30.8 mmol) PEGMEM were used.

To each flask, 34 mg of AIBN was added as an initiator, and 5 mL of THF was introduced. The reactions were continued for 2 hours at 60°C until a viscous consistency was observed. After the reaction was complete, the copolymers were precipitated twice in 200 mL of cold hexane. The upper layer of the viscous copolymers was decanted, and the remaining polymers were capped and dried in a vacuum oven for 24 hours. These samples were labeled as P1, P2, and P3 based on the monomer ratios used. The tensile strength of the polymers was then evaluated using mechanical strength tests.

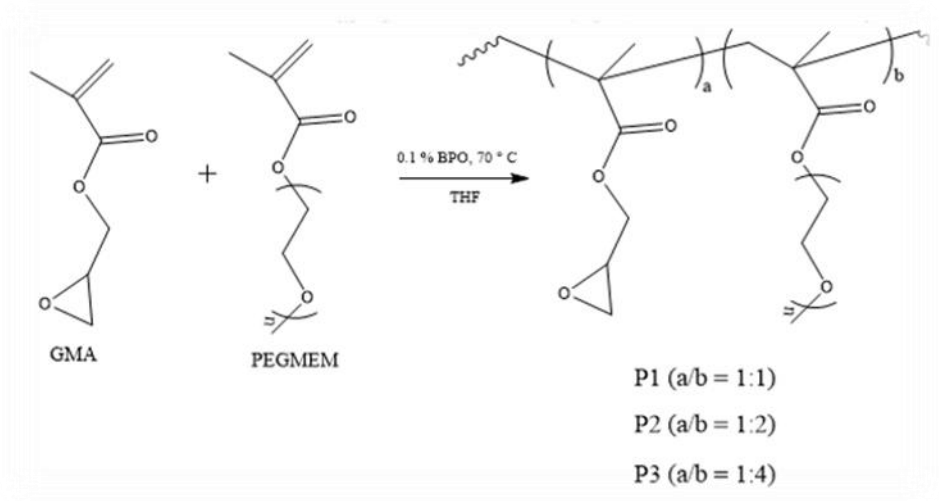


Figure 3. Synthesis of P1-P3 polymers

Curing (Crosslinking) Process

1g of p(GMA) was dissolved in 10 mL of THF. Since diaminodiphenylmethane (DADFM), the cross-linking agent, contains two amine groups, its solution was prepared by using 0.45 times the amount of polymer. This solution was applied to the prepared metal surfaces to form a 0.2 mm thick layer, which was left to dry overnight. Following this, the samples were cured for one hour at 120 °C under 6.5 MPa pressure and allowed to reach thermal equilibrium at room temperature (Figure 5). The mechanical properties of the samples, now ready for tensile testing, were evaluated using a compression and tensile testing machine.

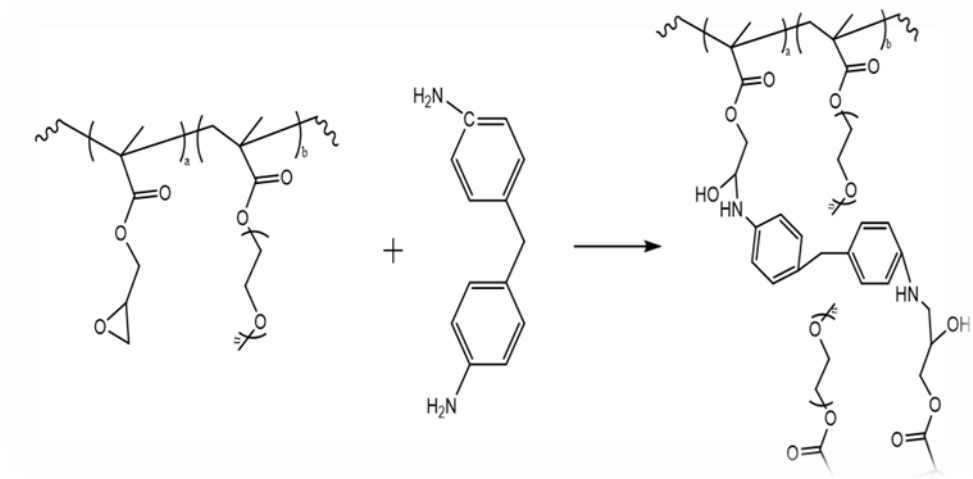


Figure 4. Epoxy ring/DADFM crosslinking

Adhesive Applications of P(GMA)

1g of PGMA was dissolved in 10 mL of methyl ethyl ketone (MEK) in a 50 mL round-bottom flask, and 0.45 moles of 4,4'-diaminodiphenylmethane (DADFM) cross-linking agent were added for each mole of epoxy group. The mixture was stirred with a magnetic stirrer until a homogeneous solution was achieved. This solution was then applied to the surfaces of 2.56.51 cm steel blocks using a dropper to form a 0.2 mm thick film, as shown in Figure 3. The samples were left to dry at room temperature for one day. Following drying, they were cured for one hour at 120 °C under 6.5 MPa pressure and then kept at room temperature until thermal equilibrium was reached. The mechanical properties of the samples, now ready for tensile testing, were assessed using a compression and tensile testing machine.

Figure 5. Application of the adhesive to metal surfaces (right and left) and hot press equipment where the curing process is performed (middle).

Mechanical Tests of the Obtained Single-Acting Adhesive Joints

Mechanical testing of the single-acting adhesive joints was conducted using a tensile compression test (Figure 4). The objective of the tensile test is to determine the elastic and plastic behavior of materials under static loads. Based on this, the aim is to optimize the mechanical properties and bonding parameters of the material. The tensile tests were carried out on three different samples prepared with PGMA using a tensile compression machine with a capacity of 250 kN. The maximum strength obtained during the tests was measured at 2.21 kN. The damages occurring on the surface as a result of the tensile test were examined using a scanning electron microscope (SEM) (Figure 6). As shown in the SEM images, the polymeric adhesive exhibited both cohesive and adhesive failure due to the applied force during the tensile-compression test.

Figure 6. SEM images of P(GMA)/DADFM cross-linked polymer and magnetite particles

Mechanical Tests

Tensile testers are devices used to assess the material properties of substances, specifically designed to determine their strength and elasticity. These machines are employed to measure various mechanical properties of materials, such as tensile strength, elongation, and overall strength. The operation of tensile testing machines involves stretching a material at a standardized rate while recording the stress-strain curve of the material. This curve illustrates the material's behavior under tension. In tensile testing, a sample of the material is placed between a pair of grippers, each equipped with jaws that securely hold the ends of the material. The distance between the jaws is then increased at a controlled speed, causing the material to stretch. Throughout the process, a load cell measures the tensile force exerted on the material. This procedure is automatically controlled by computer software, which generates graphical data to represent the material's performance during the test.

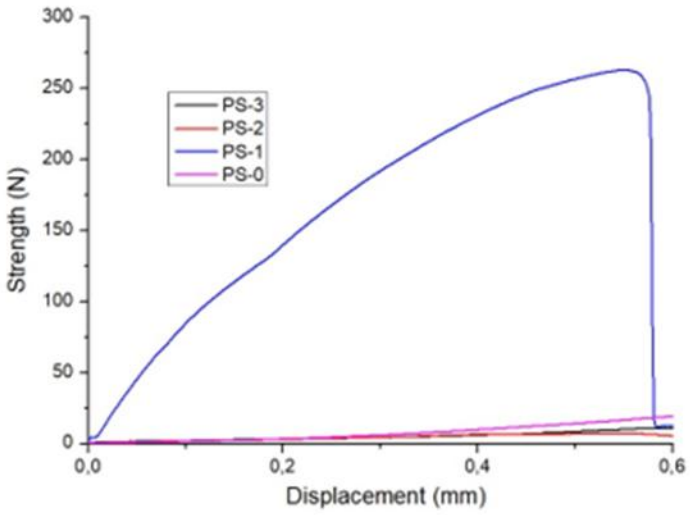
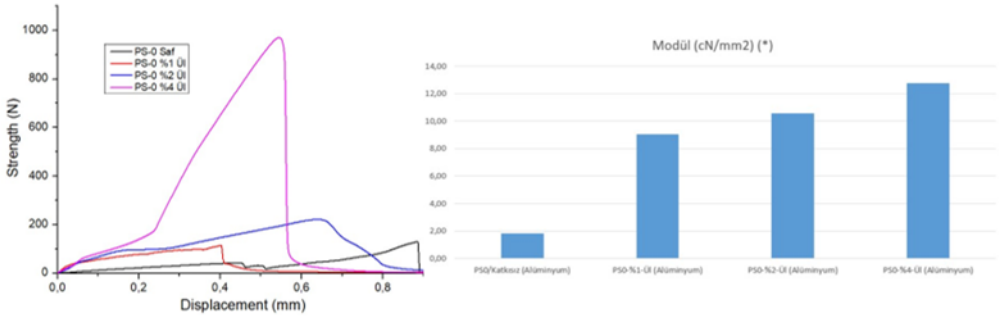


Figure 7. Elongation at break graph of PS-0/PS-3 plain polymers on steel blocks



Figüre 8. Elongation at break graph of PS-0 (% 1,2,4 Ulexite) composite polymers on aluminum blocks

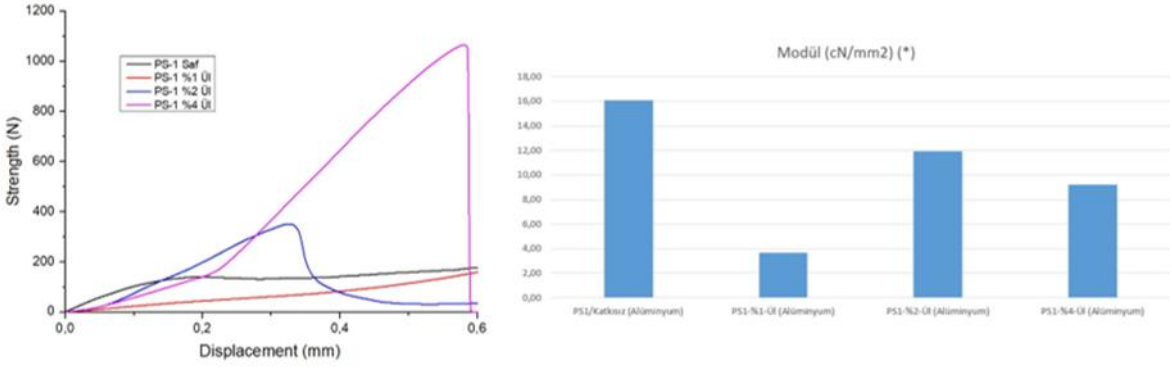


Figure 9. Elongation at break graph of PS-1 (% 1,2,4 Ulexite) composite polymers on aluminum blocks

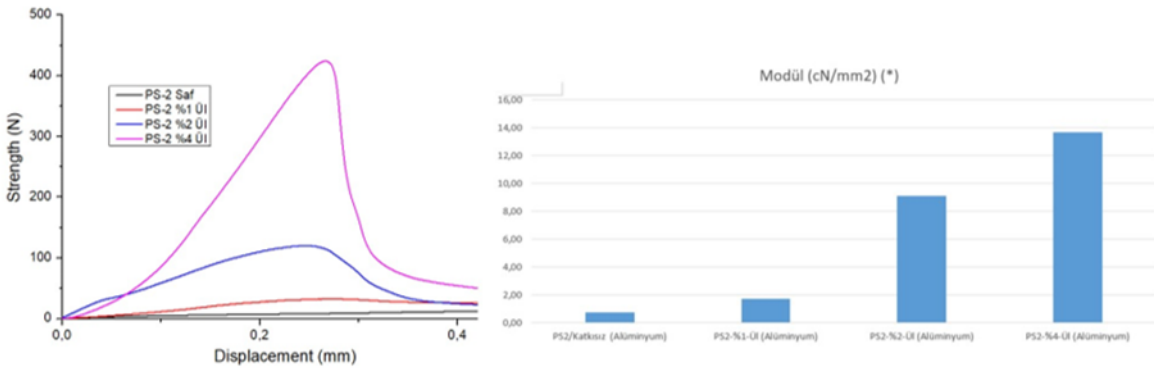


Figure 10. Elongation at break graph of PS-2 (% 1,2,4 Ulexite) composite polymers on aluminum blocks

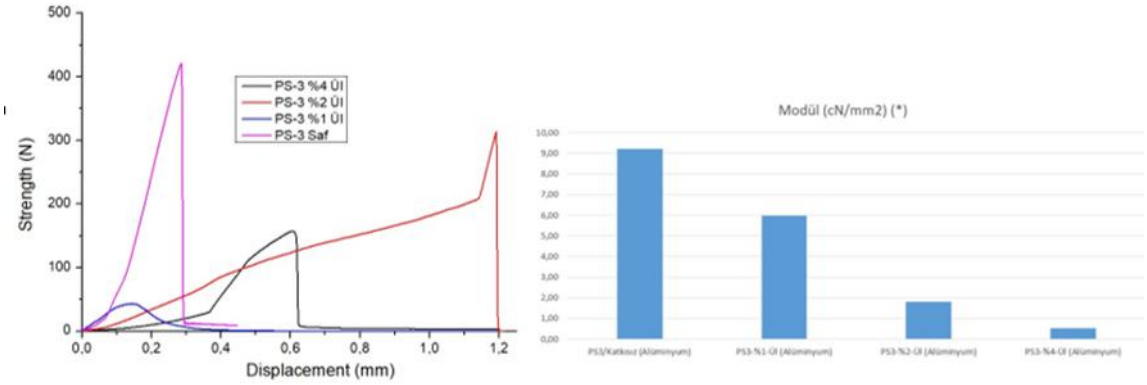


Figure 11. Elongation at break graph of PS-3 (% 1,2,4 Ulexite) composite polymers on aluminum blocks

It was observed that the addition of Ul generally caused a decrease in the strength value. The strength value of the sample without additives (421.2 N) is higher than all other additives. The addition of additives also caused a decrease in the modulus value. In the additive samples, due to the orientation formed after the stress hardening, it caused a rapid increase in strength before rupture. The strength value of the materials decreased, the elongation amount increased. While the modulus value was measured as 9.21 cN/mm^2 in the additive-free, it was measured as 0.54 cN/mm^2 in the additives. The material gained a more ductile structure. Max Strength: PS-3/Unadded (Aluminum) Max Modulus: PS-3/Unadded (Aluminum)

RESULTS

In general, the strength increased as the amount of additives increased. The most significant increase was seen in the "PS-2/ (Aluminum)" sample (from 13.4 N to 424.1 N). In contrast; the strength values of "PS3/ (Aluminum)" decreased. The strength values of the PS-2 sample is generally low. There was variability in the module values, and in some of them, a decrease in the increasing pressures was detected. The highest strength value: 1065.9 N "PS-1 %4-Ül (Aluminum)" The lowest strength value: 4.2 N.

CONCLUSION

It is a result of the linear relationship between unit elongation in elastic deformation and normal stress (tensile or compressive stress) and is defined as the stress per unit elongation. Unique new generation polymer and copolymer materials were synthesized for use in adhesive applications. It is observed that materials synthesized as adhesives increase their adhesion properties and interfacial interactions to surfaces.
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PARASITIC ANTENNA ARRAY WITH WIDE SCANNING COVERAGE FOR 5G APPLICATIONS

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ABSTRACT
In millimeter-wave 5G applications, antenna design parameters like coverage and gain are important for minimizing atmospheric and path losses. This study presents a 1 × 8 phased array antenna offering high gain and spacious coverage at 28 GHz. The array structure consists of eight parasitic patches aligned along one axis. The single antenna element contains a gap-coupled feed patch and a parasitic element. The antennas are simulated on a Computer Simulation Technology (CST) solver using Flame Retardant-4 (FR-4) as the substrate material with a thickness of 0.699 mm. The simulation results of the solo element exhibited a low return loss of -23 dB and a VSWR of 1.2 at 28 GHz. The parasitic element contributed to enhancing the resultant gain of the single antenna from 6.5 to 7.7 dBi at the operating frequency. The simulated array increased the gain to 15.2dBi with a side lobe level of -14.9 dB and beam-steering coverage of ±58° at the frequency of interest. The proposed array achieved good interelement isolation of less than -23 dB over the band of interest. The simulation results show that the array antenna achieves a good 10-dB bandwidth, satisfying the 5G requirements. The findings showed that the proposed array might be a good option for 5G applications.
Keywords: Beam steering, 5G, Millimeter wave, 28 GHz, Microstrip patch antenna, Phased array antenna

1. INTRODUCTION

Fifth Generation (5G) systems play a crucial part in handset communication development by working at the millimeter wave frequency band. Wireless mobile communication technologies have evolved very quickly due to the need for high-data traffic services. The millimeter-wave high-frequency band satisfies such services because of its wide bandwidth. However, the atmospheric condition and signal attenuation become highly significant at this frequency band. Recently, the Federal Communications Commission (FCC) revealed the spectrum (27.5–28.35 GHz) as a licensed millimeter wave band for 5G communication. Then, FCC proposed the 28 GHz band as one of the millimeter wave frequency bands dedicated to 5G cellular communication since the atmospheric sorption in this frequency band does not considerably lead to further free-space path loss. [1-9].

High-gain beam steerable arrays must be placed at base stations and mobile devices to overcome high propagation losses. In addition, the antenna array must have large steering angle to stabilize the connection in difficult environments. A phased array antenna is a perfect solution for tackling millimeter-wave frequency band problems because it can offer directional beam steering features. To satisfy the 5G mm-wave requirements, a new, high-gain, beam-steerable, and wide-coverage phased array design suitable for mobile terminals is required [10-14].

This study proposes a high-gain phased array antenna with wide steering angle to be used in 5G applications. The array consists of eight rectangular-microstrip patch antennas containing parasitic elements. The array elements are arranged linearly and spaced uniformly from each other with interelement spacing close to 0.5 λ. In main beam steering, progressive phase shifters excited the elements of the array. The beam steering was investigated by modifying the phase shift of the radiating elements. The CST Microwave Studio 2019 solver was utilized to analyze and measure the antenna performance.

2. ANTENNA DESIGN AND PARAMETERS

The top layer of the single-element consists of two rectangular radiating components, a microstrip, and a parasitic patch separated by distance (dp). A top layer of the single antenna element is showed in Figure 1. The parasitic-element was added to make the antenna resonate at 28 GHz and enhance the resultant gain. Gap-coupled feeding method is used in this design to improve the bandwidth of the antenna. The patch and ground layers of the solo antenna were made of pure copper. The top layer was placed on a Flame Retardant-4 (FR-4) substrate with dimensions of 11.2×8.75× 0.699 mm^3, a 4.3 dielectric constant, and a loss tangent of 0.025. The parameter list of the single antenna element is shown in Table 1.

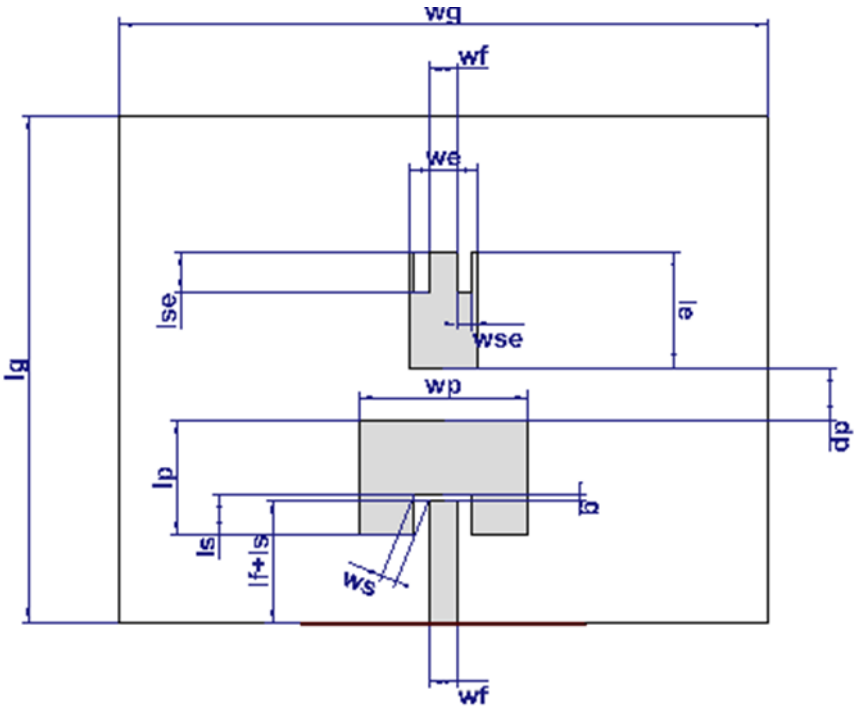


Figure 1. Top view of the single element design

Table 1. Parameters of antenna design

Parameter	**Dimension (mm)**
Single element	
Patch Length (lp)	2
Patch Width (wp)	2.9
Substrate Length or ground Length (lg)	8.75
Substrate Width or ground Width (wg)	11.2
Dielectric constant of the substrate	4.3
Height of the substrate	0.699
Height of the conductor	0.035
Transmission line Width (wf)	0.5
Transmission line Length (lf)	1.5
Length of patch slot (ls)	0.715
Width of patch slot (ws)	0.25
Parasitic patch length (le)	2
Parasitic patch width (we)	1.2
Length of parasitic patch slot (lse)	0.715
Width of parasitic patch slot (wse)	0.25
Distance between patches (dp)	0.9
Gap (g)	0.1
Array	
Array length (l)	8.75
Array width (w)	53.2
Interelement spacing (s)	5.5

The proposed array antenna consists of eight equally spaced elements, as shown in Figure 2. The patch elements are placed next to each other in a linear fashion. The overall dimensions of the proposed array are 53.2*8.75*0.699 mm^3. The patch elements are separated by s distance. The parameter list of the proposed array is shown in Table 1. The proposed linear array employs the progressive phase excitation to steer the main beam over the visible region [15]. Beam steering can be achieved by changing the phase shift of each element to obtain the maximum steering angle.

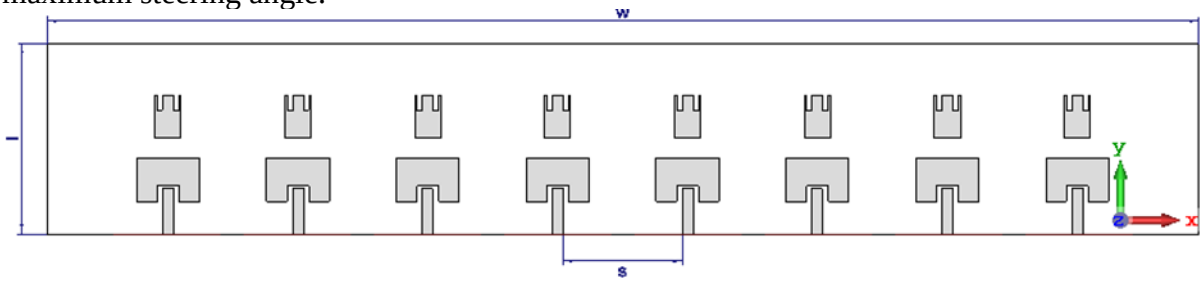


Figure 2. Proposed antenna array design

3. SIMULATION RESULTS

a. Antenna Element

The radiation properties of a single-element with/without a parasitic-element were examined in terms of s-parameter, 10-dB frequency bandwidth, VSWR, and gain. Figure 3 depicts the s11 plot of the single-element. As, shown, the antenna has an s11 of -23 dB at 28 GHz. A reflection coefficient of less than –10 dB is obtained over the frequency range (27–29.8) GHz. Figure 4 illustrates the VSWR graph of the solo antenna. This design yielded a good VSWR of 1.2, which is ≤ 2. Figure 5 displays the 3D plot of far-field gain for a single patch. The antenna element exhibits a gain value of 7.7 dBi. Figure 6 demonstrates the 3D plot of far-field gain for a single patch without parasitic element. The antenna without parasitic element achieved a gain of 6.5 dBi. The gain was increased by 1.2 dBi at 28 GHz. The single-element design with the highest gain (with parasitic element) is chosen for array design.

b. Array Antenna

The array antenna's radiation properties were checked in terms of gain, radiation pattern, and S-parameters. Figure 7 shows the S-parameters (s11-s81) of the proposed array. As shown, the array offers 2.8 GHz bandwidth which covers the 5G spectrum (27.5–28.35 GHz). For beam steering, we must check the isolation performace between elements. The proposed array resonates at 28 GHz with less than -23.5 dB mutual-coupling between elements. This implies that the array is suitable for beam steering. Figure 8 displays the 3D plot of far-field radiation pattern for the simulated array. As depicted, the main beam of the array becomes more focused and directed after integrating the radiation patterns of the array elements. The array radiates at angle of 32° with a gain of 15.2 dBi and a side lobe level of -14.9 dB. Therefore, the radiation coverage needs to be widened by applying a beam steering mechanism. The array achieved the maximum steering angle at a ±180° phase shift, as shown in Figure 9. The proposed array can steer the main beam from –58° to +58°.

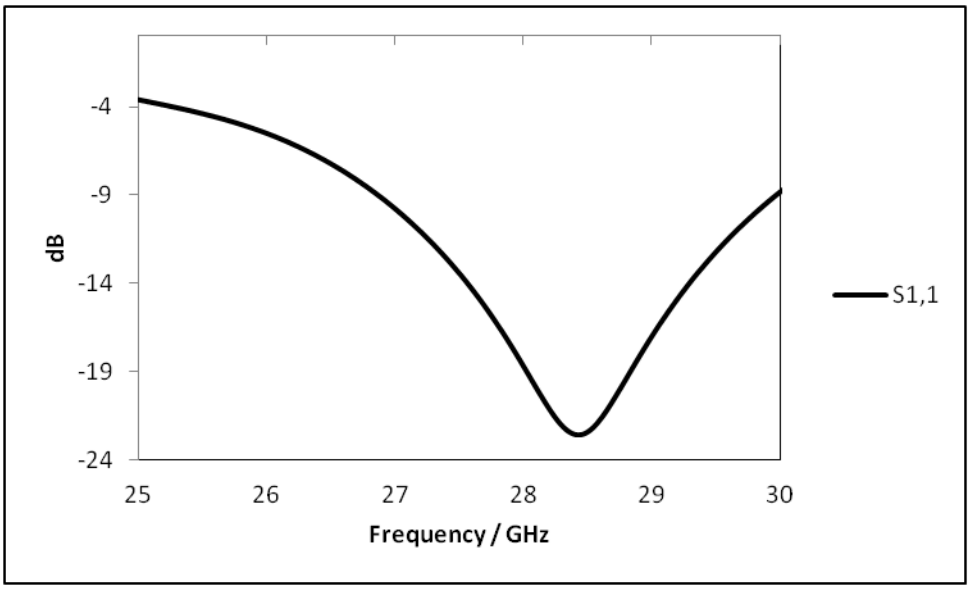


Figure 3. S_{11}-parameter of the single antenna element

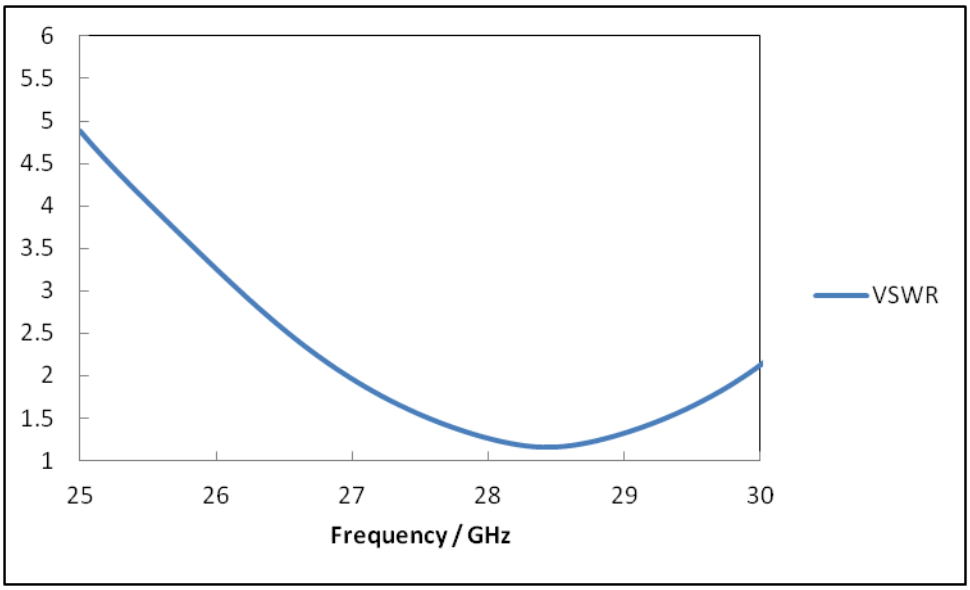


Figure 4. VSWR of the single antenna element

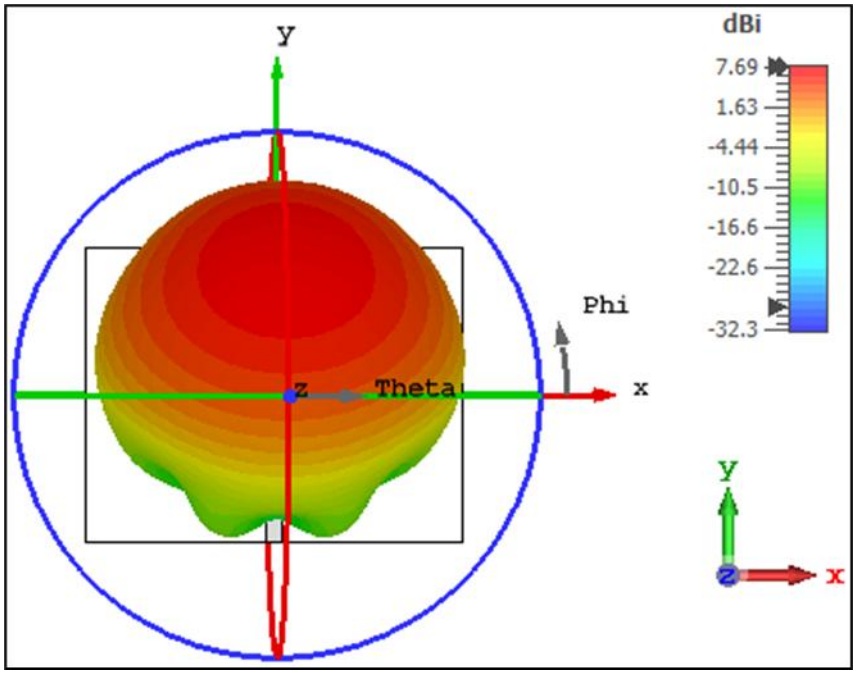


Figure 5. 3D far-field gain plot for a single antenna element with parasitic element

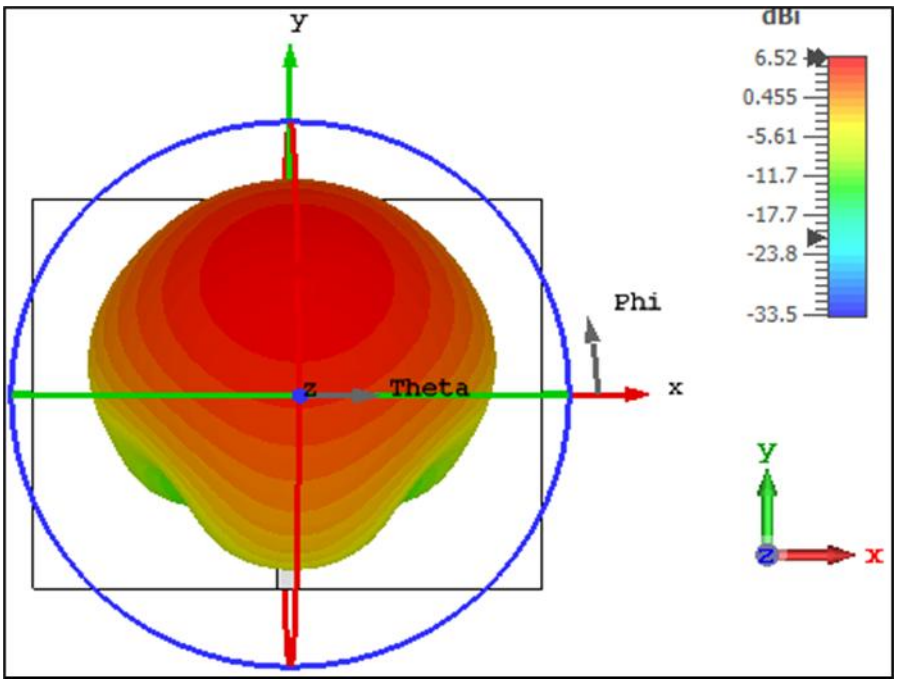


Figure 6 3D far-field gain plot of a single antenna element without a parasitic element

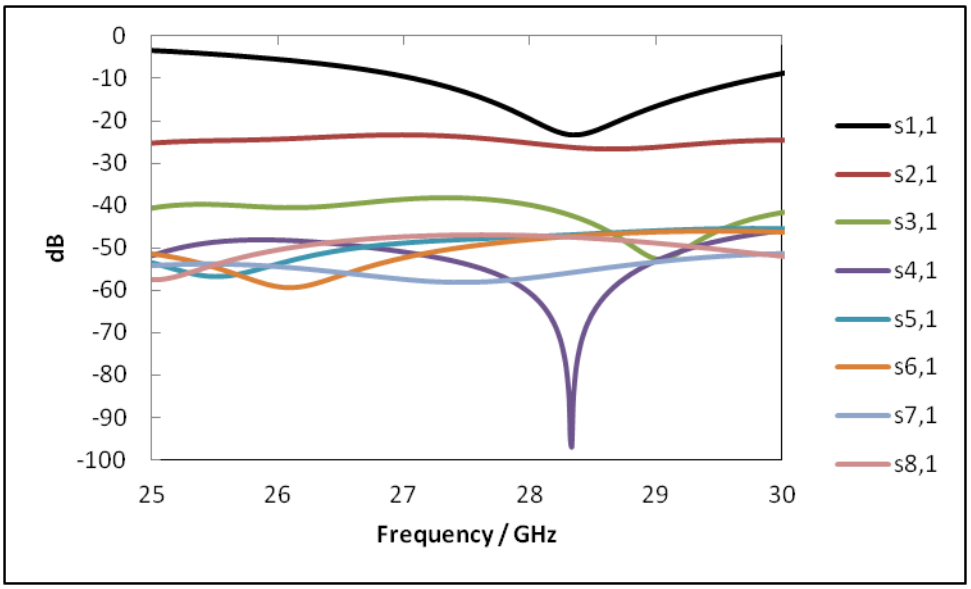


Figure 7. S-parameters of the proposed array

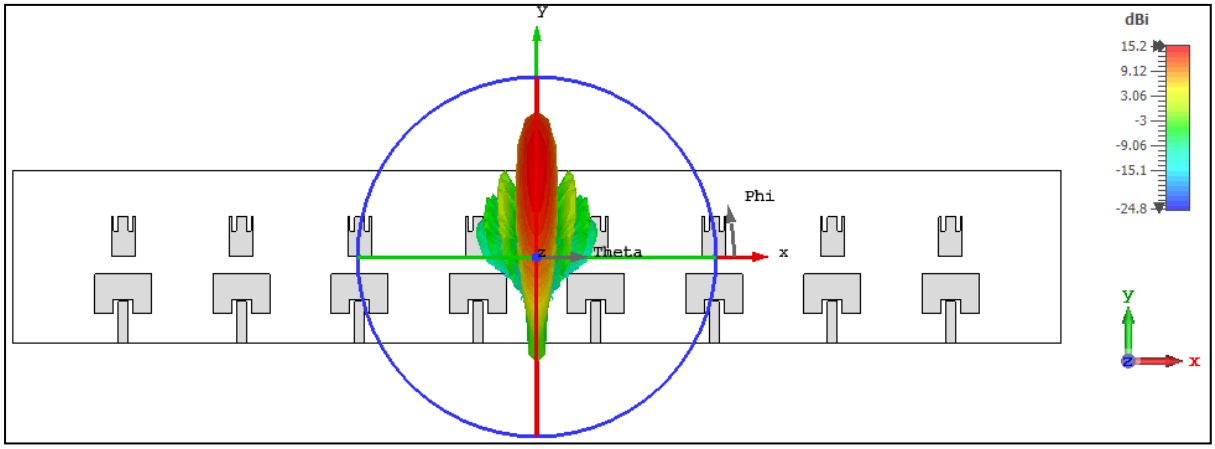
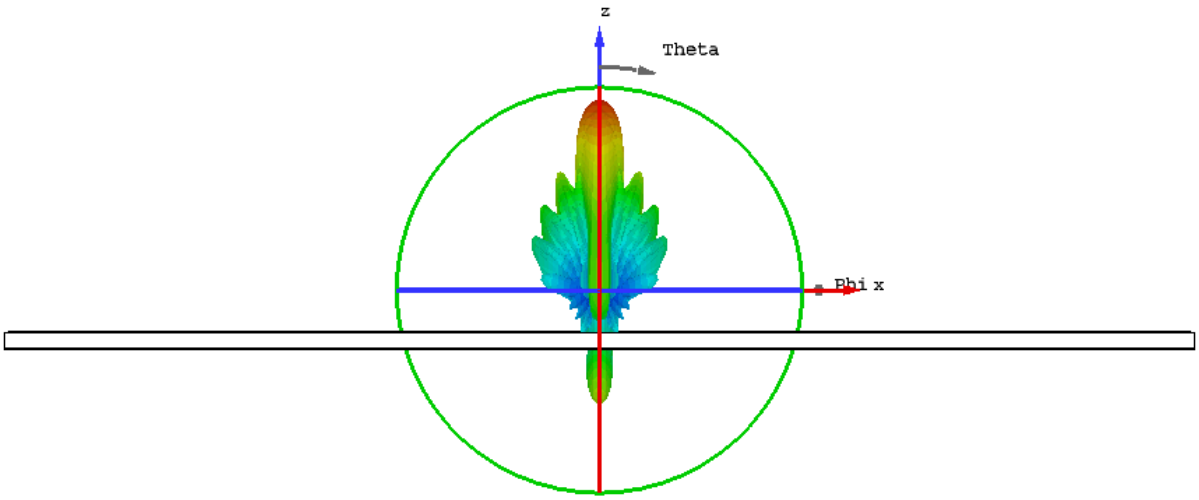
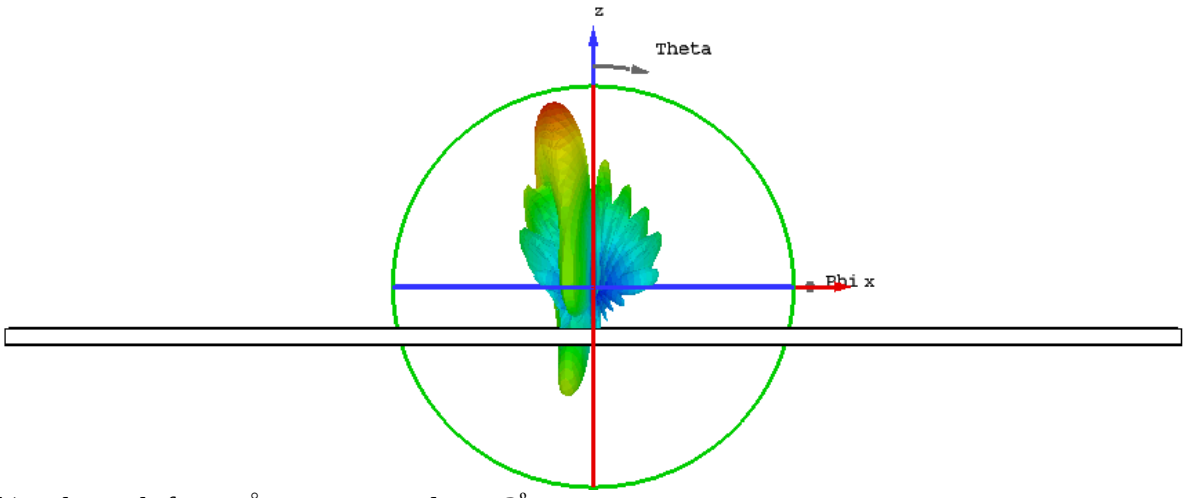


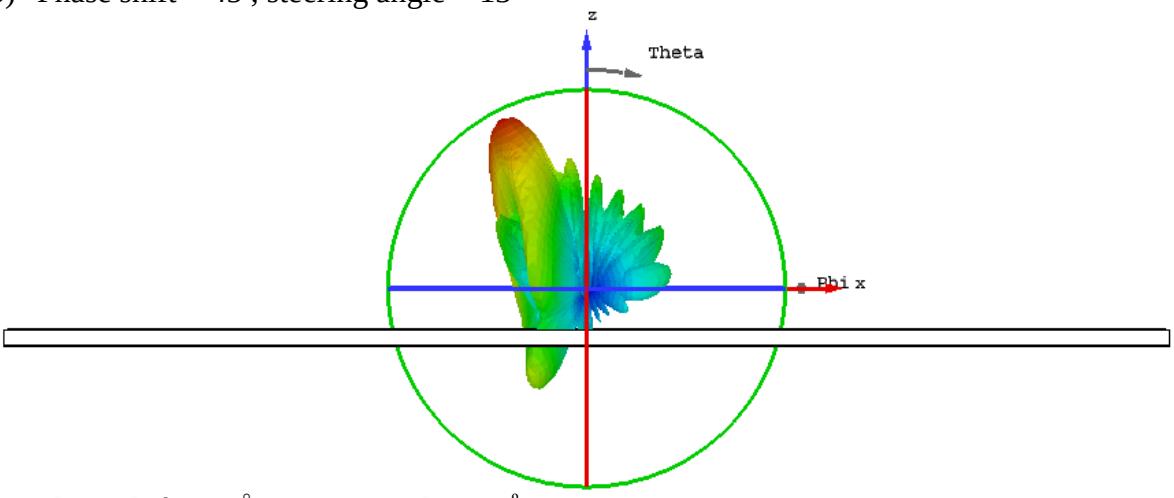
Figure 8. 3D plot of far-field gain of the proposed array



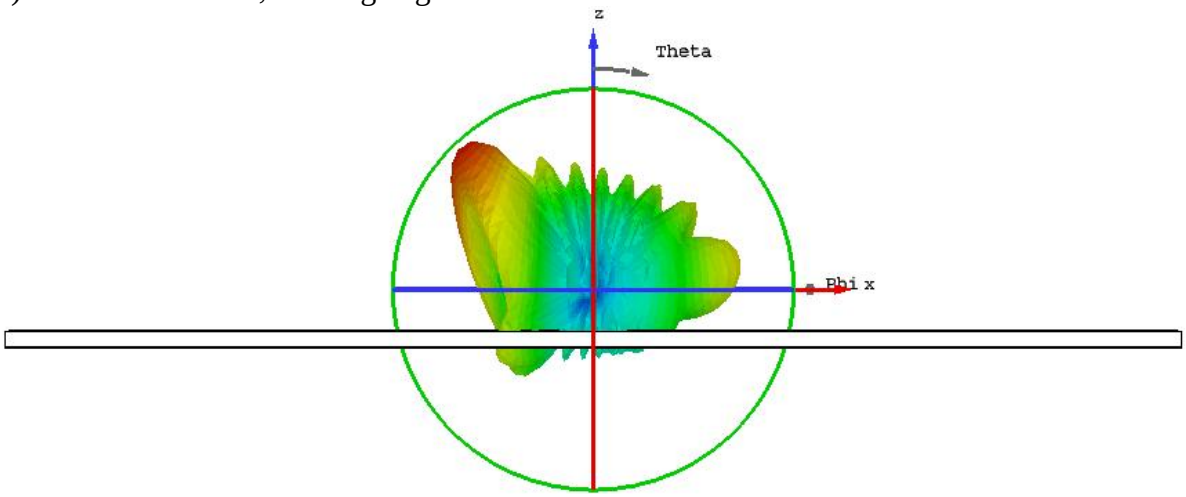
a) Phase shift = 0°, steering angle = 0°



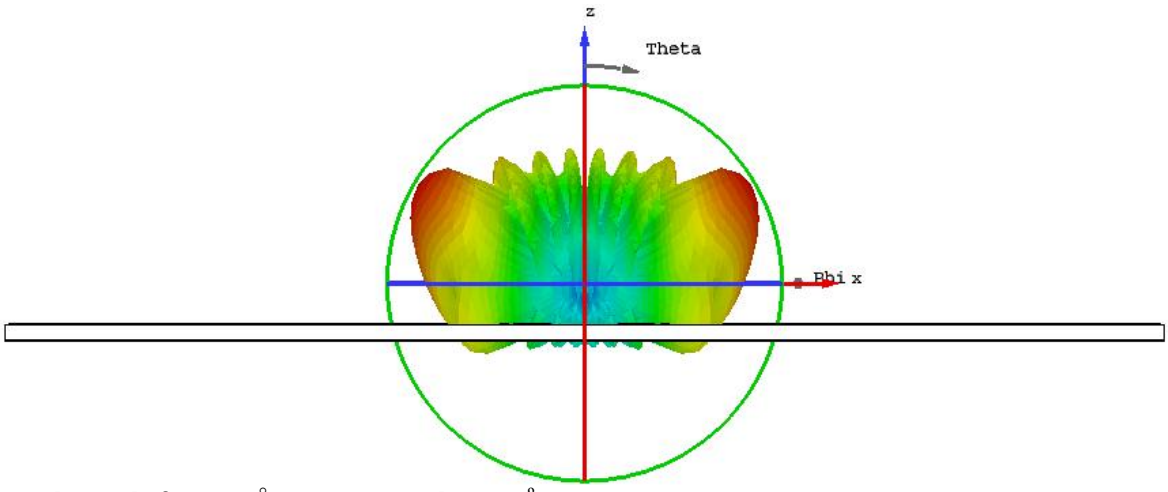
b) Phase shift = 45°, steering angle = 13°



c) Phase shift = 90°, steering angle = 26°



d) Phase shift = 140°, steering angle = 42°



e) Phase shift = 180°, steering angle = 58°

Figure 9. Beam steering investigation of the proposed array

4. CONCLUSIONS

This study covered two parts of antenna design and simulation at 28 GHz. The first section includes a single rectangular coupled-feed patch antenna with a parasitic element. The simulated antenna had good s11 and VSWR. The results revealed that adding the parasitic element into a single-element design raised the gain from 6.5 to 7.7 dBi. The simulation results of the single-element showed that the single-element can be a perfect candidate for use in a variety of array structures in 5G mobile applications. The second part of this study involved designing and analyzing a phased antenna array with beam steering capability. The simulated array exhibited low isolation between elements. The array reached a gain of 15.2 dBi and a coverage angle of ±58°. The proposed phased array satisfies the 5G requirements and can be the best fit for 5G handset applications.

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ACCESS AND UTILIZATION PATTERNS OF AGRICULTURAL CREDIT AMONG SMALLHOLDER MAIZE FARMERS IN BIDA LOCAL GOVERNMENT AREA, NIGER STATE

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ABSTRACT
The utilization of agricultural credit plays a crucial role in enhancing the productivity and income of farmers, particularly in developing regions. This study examined access and utilization pattern of agricultural credit among small holder maize farmers in Bida Local Government Area, Niger State. Specifically, the study describe the socio-economic characteristics of maize farmers, evaluate the sources of agricultural credit available to maize farmers, examine the accessibility of these credit sources, analyze the impact of agricultural credit on maize production, and identify the challenges faced by farmers in accessing credit. A multi-stage sampling technique was employed to select 100 maize farmers for the study. Data collected were analyzed with the aid of frequency counts, percentages and mean. The result of the study revealed that majority (64% and 80%) of the respondents were male and had one form of education or the other with a mean age of 32 years. 56% were married with a mean of 12 years of farming experience respectively. On the source of agricultural credit, majority (87%) strongly agreed they accessed loan from bank. The process of obtaining credit was perceived as easy by 37% due to collateral requirement. On the agricultural credit utilization, majority (74%) of the respondents had strongly agreed that increase there was increase in their level of agricultural production. On the challenges faced by respondents, are difficult in meeting collateral requirement for credit and Interest rates on loans are too high. The study concluded that they are valuable insight on their accessibility and impact of agricultural credit in maize production in the study area. It is therefore recommended that, financial institution should simplify the credit application process to small holder maize farmers by reducing collateral requirement and interest on loan.

Introduction

Maize, is one of staple food millions of Nigerian populations, it also serves as a crucial raw material for various industries, including animal feed, brewing, and starch production (IFPRI, 2021). Maize is grown across the country, with significant production in states like Niger, Kaduna, and Kano (National Bureau of Statistics, 2021). Its adaptability to diverse agro-ecological zones and its relatively short growing period make it a preferred crop among farmers (IFPRI, 2021).

Despite the crop's importance, maize production in Bida Local Government Area (LGA) of Niger State faces numerous challenges such as poor soil fertility, pests and diseases, inadequate infrastructure, and, notably, limited access to agricultural credit (Olagunju, 2020; Umar & Kolo, 2018). Lack of access to credit also posed a significant barrier to agricultural productivity, as it hampers the ability of farmers to invest in essential inputs and technologies (Adebayo, 2019; Olagunju, 2020).

Agricultural credit is essential for improving productivity and sustaining agricultural enterprises. It provides farmers with the necessary funds to purchase inputs such as seeds, fertilizers, pesticides, adopt new technologies, and cover operational costs such as labor and transportation (Central Bank of Nigeria, 2018; Ololade & Olagunju, 2019). Credit facilities can come from various sources, including formal financial institutions (banks), informal lenders, cooperatives, and government programs (Ajayi, 2020). Effective utilization of these credit facilities can lead to increased agricultural output, higher incomes for farmers, and overall economic growth (Central Bank of Nigeria, 2018; Ajayi, 2020).

However, the utilization of agricultural credit among maize farmers in Bida LGA has been suboptimal. Factors contributing to this include stringent loan conditions, high-interest rates, lack of collateral, and limited awareness of available credit facilities (Anigbogu et al., 2021). Additionally, bureaucratic hurdles and inefficiencies in the credit disbursement process further discourage farmers from accessing these financial resources (Ajayi, 2020; Umar & Kolo, 2018).

This suboptimal utilization of agricultural credit has significant implications for the productivity and economic well-being of maize farmers in Bida LGA. Without adequate credit, farmers struggle to purchase quality inputs or adopt improved farming practices, resulting in lower yields and incomes (Musa, 2019; Ijaiya & Abdullahi, 2020). This, in turn, affects the broader agricultural value chain and the local economy, as lower productivity reduces the availability of maize for both consumption and industrial use (Musa, 2019; Yusuf, 2021).

Addressing these challenges through targeted interventions and supportive policies is crucial for enhancing agricultural productivity and improving the livelihoods of maize farmers in the region (Afolabi, 2019; Bolarinwa & Fakoya, 2019). Therefore, this study seek to assessed the utilization of agricultural credit among small holder maize farmers in Bida Local Government Area of Niger State. The specific objectives of the study were to:

i. describe the socio-economic characteristics of small holder maize farmers in Bida local government
ii. evaluate the sources of agricultural credit available to small holder maize farmers in the study area;
iii. examine the small holder maize farmers access and utilization of agriculture credits in the study area; and
iv. identify the challenges faced by small holder maize farmers in accessing agricultural credit.

Methodology

Study Population

The target population for this study comprises smallholder maize farmers in three purposively selected communities within Bida Local Government Area (LGA), Niger State: Bida, Gabas, and Wushishi. These communities were selected based on their known engagement in maize production and their varying levels of access to agricultural credit institutions.

Sample Size Determination

A total of 100 smallholder maize farmers were selected for the study. The choice of a 100-respondent sample size is appropriate for a descriptive cross-sectional study aimed at identifying patterns and perceptions, particularly when working with a relatively homogenous group (maize farmers) in a defined geographical area. This sample size allows for sufficient variability while maintaining manageability and cost-effectiveness for field data collection.

Sampling Procedure

A multi-stage sampling Procedure was adopted for the selection of respondents:

Stage 1: Purposive Selection of three communities Bida, Gabas, and Wushishi based on their agricultural significance, accessibility, and the presence of active maize farming populations.

Stage 2: Proportional allocation to ensure fair representation, 100 respondents were proportionally distributed across the three communities based on their estimated maize farming populations.

Stage 3: Random Sampling of Respondents within each selected community, a list of registered maize farmers was obtained from local farmer associations. From these lists, farmers were selected using simple random sampling without replacement, ensuring each eligible farmer had an equal chance of being included in the study. Bida: 45 farmers (45%),Gabas: 30 farmers (30%), Wushishi: 25 farmers (25%)

Results and Discussions

Demographic and Socioeconomic Characteristics of Respondents

The demographic profile of the respondents, as presented in Table 1, reveals that 64% of the participants were male, indicating a slightly higher representation of men in maize farming activities in the study area. This aligns with prior findings that agricultural labor, particularly in sub-Saharan Africa, tends to be male-dominated, especially in crop production (FAO, 2011).A significant majority (71%) of the respondents were between the ages of 26 and 45 years, suggesting a predominantly middle-aged farming population. This age group is often considered economically active and physically capable of managing labor-intensive farming activities, consistent with findings by Ayanwuyi et al. (2010), which highlighted that youth and middle-aged adults dominate farming because of their agility and strength. Furthermore, 80% of the respondents had some form of formal education, suggesting that most had access to educational opportunities. While a notable minority lacked formal education, the general literacy level may contribute positively to the adoption of improved agricultural practices and technologies (Asfaw & Admassie, 2004). Education is often correlated with increased productivity and income among farmers. With 56% of respondents being married, it is evident that most households are likely operating within a stable family structure. Married individuals are often more likely to have greater labor availability and support systems, which could enhance farming productivity (Amaza et al., 2006).Additionally, 73% of respondents reported having household sizes between 1–5 members, suggesting smaller household structures. Smaller households may face labor shortages, which could influence the scale and efficiency of farm operations (Ellis, 2000), but they may also have lower consumption pressures. In terms of farming experience, 36% of respondents had over 16 years of experience in maize

cultivation. This indicates a highly experienced farming population, which is a positive predictor for the successful adoption of innovations and risk management in agriculture (Knowler & Bradshaw, 2007).

The income distribution reveals that 74% of respondents earned between ₦401,000 and ₦800,000 annually from maize farming, while a minority (2%) earned above ₦1.1 million. This suggests that maize farming is a relatively profitable venture for many respondents, although income disparities exist. Such income levels underscore the potential of maize farming as a viable source of livelihood, echoing findings by Ogunniyi & Ojedokun (2012), who observed that maize farming significantly contributes to rural household income.

Despite the prominence of maize farming, only 25% of respondents identified it as their primary income source, while 59% relied on other agricultural ventures. This reflects a diversification strategy aimed at income stabilization and risk reduction, which is common among rural households (Barrett et al., 2001).

Geographically, most respondents (59%) were located in Bida, with fewer in Gaba (26%) and Wushishi (15%). This distribution may reflect the relative accessibility or maize production viability in Bida. Regional clustering of agricultural activities often correlates with infrastructural availability and market proximity (World Bank, 2007).

Finally, the data show a stable residency pattern, with 76% having lived in the community for 11–20 years. Long-term residency is often associated with better social cohesion and deeper local knowledge, which can facilitate collective action and resource sharing among farmers (Pretty, 2003).

Table 1: Socio-Economic Characteristics of maize farmers

Variable	Frequency (F)	Percentage (%)	Mean	Standard Deviation(SD)
Gender				
Male	64	64		
Female	36	36		
Age				
Below 25	27	27		
26-35	32	32	32.48	6.11
36-45	39	39		
46 Above	2	2		
Education Level				
No Formal Education	20	20		
Primary Education	11	11		
Secondary School	27	27		
Tertiary Education	42	42		
Marital Status				
Single	33	33		
Married	56	56		
Divorced	11	11		
Household Size				
1-5	73	73		
6-10	14	14	5.65	5.07
16-20	13	13		
Years of Experience in Maize Farming				
1-5	30	30		
6-10	16	16	12.32	6.35
11-15	18	18		
16 and Above	36	36		

Source: Field survey, 2024

Socio-Economic characteristics Continued

Income from Maize Farming				
#100,000	11	11		
#101,000 – #400,000	13	13	₦194,500	₦203,702.60
#401,000 - #800,000	74	74		
Above 1.1 million	2	2		
Main Source of Income				
Maize Farming	25	25		
Other Agriculture	59	59		
Business	14	14		
Employment	2	2		
Location				
Bida	59	59		
Gaba	26	26		
Wushishi	15	15		
Number of Years Residing in the Community				
11-20 years	76	76		
21-30 years	24	24		

Source: Field survey, 2024

The data on sources of agricultural credit in table2 reveals that a majority of respondents are aware of various agricultural credit sources, with 87% either strongly agreeing or agreeing. Banks appear to be the most accessed source of credit, with 98% of respondents having obtained credit from banks, which are considered more reliable than other sources by 60%. In contrast, microfinance institutions are less utilized, as 65% of respondents remain neutral on accessing credit from them, reflecting limited engagement or accessibility in this area. Government programs and cooperatives play a moderate role in providing credit, though perceptions vary. While 32% of respondents agree they have accessed credit from government programs, a significant 41% are neutral, suggesting that more awareness or accessibility could be beneficial. Cooperatives are a primary source of credit for 51% of respondents, though a notable portion, 31%, remains neutral. Similarly, only 14% of respondents strongly agree they have received grants from agricultural organizations, indicating that grant access is still somewhat limited. Finally, informal credit sources, such as borrowing from family and friends, are preferred by many due to fewer requirements, with 43% of respondents favoring informal options. The accessibility of credit has slightly improved through community initiatives, with 41% of respondents agreeing, though formal credit sources, such as banks, are perceived to offer better interest rates (84% agreement).

Table 2: Main Sources of Agricultural Credit

S/N	Items	SA (%)	A (%)	N (%)	D (%)	SD (%)	x̄
1	I am aware of different sources of agricultural credit	14.0	73.0	13.0	-	-	2.0
2	I have accessed credit from banks	25.0	73.0	2.0	-	-	2.2
3	I have accessed credit from microfinance institutions	13.0	-	65.0	22.0	-	2.0
4	I have accessed credit from government programs	20.0	12.0	41.0	25.0	2.0	2.3
5	I have accessed credit from cooperatives	14.0	28.0	31.0	2.0	25.0	2.4
6	I have borrowed money from family and friends for farming	28.0	11.0	26.0	13.0	22.0	2.7
7	I find banks' credit more reliable than other sources	-	60.0	11.0	16.0	13.0	2.0
8	Government programs provide affordable credit	14.0	22.0	52.0	12.0	-	2.0
9	I prefer informal credit sources due to fewer requirements	30.0	13.0	34.0	11.0	12.0	2.6
10	I have received grants from agricultural organizations	13.0	32.0	41.0	14.0	-	2.4
11	Cooperative societies are a primary source of credit for me	12.0	39.0	29.0	-	20.0	2.4
12	Access to credit has increased through community initiatives	11.0	30.0	32.0	13.0	14.0	2.3
13	Formal credit sources have better interest rates	2.0	84.0	14.0	-	-	2.0
14	Microfinance institutions are accessible in my area	-	42.0	45.0	13.0	-	2.0
15	Financial institutions inform farmers about credit options	-	61.0	25.0	14.0	-	2.0

Source: Field Survey, 2024

The data on accessibility of agricultural credit in table 3 indicated a low mean score of 2.8, with only 12% strongly agreeing and 25% agreeing, indicating that most farmers do not find the credit application process straightforward. This aligns with findings from Yeboah & Jayne (2023), who argue that the formal financial sector still lacks the capacity to simplify credit access procedures for smallholders. A significant 64% agreed that they face challenges with collateral requirements, and only 37% found documentation manageable ($\bar{x}$ = 2.6). This confirms that asset-based lending is a major exclusionary practice in rural areas, as noted by Demirgüç-Kunt et al. (2022) who reported that 30–50% of potential borrowers in low-income countries are excluded due to lack of collateral. Despite a moderate awareness about the application process ($\bar{x}$ = 2.7), the score for having received training was relatively low ($\bar{x}$ = 2.4), with 14% strongly disagreeing. This suggests a gap in financial literacy, corroborated by (FAO ; 2023 which emphasized that education and training in credit access are critical to improving uptake and loan repayment behavior. Proximity of financial institutions ($\bar{x}$ = 2.6): Only 39% agree this is an issue, but a combined 47% are neutral or negative, showing inconsistent access. Timeliness of processing ($\bar{x}$ = 2.3) with only 27% strongly agreeing, delays are a concern. access to credit counseling ($\bar{x}$ = 2.9) .Access to guidance and successful approvals are limited, which echoes (World Bank (2023) concerns over financial institutions' outreach strategies in rural zones.

Interestingly, 62% agreed that they find it easier to obtain credit through informal sources ($\bar{x}$ = 2.4). This indicates a reliance on community-based lending, cooperatives, or moneylenders often with less bureaucratic barriers but higher risks. This trend is consistent with findings by (Mabeyo et al.(2023) on the continued dominance of informal finance in sub-Saharan Africa. The perception of transparency ($\bar{x}$ = 2.5) and advertising of credit opportunities ($\bar{x}$ = 2.9) is low. With 59% disagreeing or strongly disagreeing that credit is well advertised, outreach efforts by financial institutions and government bodies appear insufficient.

Table 3:Accessibility of Credits to farmers

S/N	Items	SA (%)	A (%)	N (%)	D (%)	SD (%)	x̄
1	The process of obtaining credit is easy	12.0	25.0	13.0	30.0	20.0	2.8
2	I face challenges with collateral requirements for credit	14.0	64.0	2.0	-	20.0	3.0
3	Interests on credit are affordable	-	16.0	57.0	27.0	-	2.7
4	I have adequate knowledge on applying for credit	14.0	53.0	13.0	-	20.0	2.7
5	I have received training on accessing credit	26.0	48.0	12.0	-	14.0	2.4
6	Proximity of financial institutions affects my credit access	-	39.0	14.0	27.0	20.0	2.6
7	I have faced rejection when applying for credit	-	42.0	33.0	-	25.0	2.6
8	The application process for credit is transparent	-	64.0	20.0	16.0	-	2.5
9	My credit application has been processed on time	27.0	28.0	25.0	20.0	-	2.3
10	I understand the terms and conditions of credit	12.0	64.0	11.0	-	13.0	2.4
11	I have access to credit counselors	13.0	28.0	14.0	45.0	-	2.9
12	My credit history affects my access to credit	-	34.0	51.0	15.0	-	2.7
13	The documentation for credit applications is not cumbersome	14.0	23.0	36.0	13.0	14.0	2.6
14	Credit facilities are advertised adequately in my area	11.0	2.0	28.0	39.0	20.0	2.9
15	I find it easier to obtain credit through informal sources	30.0	32.0	38.0	-	-	2.4

Source: Field Survey, 2024

The data collected on the challenges associated with accessing agricultural credit in table 4 highlight critical constraints faced by smallholder farmers. A universal challenge identified was the requirement for collateral, with 100% of respondents reporting difficulty in meeting collateral obligations, and 75% indicating agreement or strong agreement on the severity of this barrier. This underscores the persistent structural barrier to credit access in rural agricultural contexts, where farmers often lack formal assets that can serve as acceptable collateral.

Interest rates also emerge as a significant concern. Although only 54% of respondents expressed neutrality or agreement regarding the impact of interest rates, this suggests a degree of uncertainty or dissatisfaction with current lending terms, potentially reflecting variability in interest rate comprehension or inconsistency in loan conditions.

Another critical challenge is the lack of access to information about available credit facilities. More than half of the respondents (53%) indicated a neutral stance, possibly reflecting limited awareness or understanding, which may in turn inhibit credit utilization. Furthermore, the credit application process was perceived as complex and time-consuming by 86% of the respondents, pointing to bureaucratic inefficiencies and procedural barriers that discourage formal credit engagement.

Access to financial institutions remains limited, with 52% of respondents affirming restricted access, and 20% strongly disagreeing highlighting spatial or infrastructural disparities within the LGA. Additionally, 74% of farmers characterized the documentation process as tedious, which may reflect both a low level of administrative support and a mismatch between institutional expectations and local literacy or record-keeping practices. Distrust between farmers and financial institutions was a recurring theme, contributing to credit market failures. Notably, 38% of respondents indicated that their previous credit history had negatively influenced current access, suggesting the presence of rigid lending criteria and possible punitive assessments by financial institutions.

Concerns about the relevance and adequacy of credit facilities were also prevalent. A substantial proportion (71%) reported that existing credit products are not tailored to the specific requirements of maize farmers, which may reflect a one-size-fits-all approach by lenders that fails to address the unique cash flow and input cycles of particular crops. Similarly, 41% of respondents were neutral regarding the flexibility of repayment schedules, implying a lack of adaptable repayment structures. Perceived discrimination in credit application processes was alarmingly high, with 89% reporting experiences of unfair treatment, which could stem

from socio-economic, gender, or ethnic biases embedded in financial service delivery. Moreover, 67% of respondents agreed that current financial literacy initiatives are insufficient, underscoring the need for targeted educational programs to improve credit comprehension and utilization.

Loan amounts were commonly perceived as inadequate relative to farming requirements, while support from agricultural extension services was also found wanting, with 71% of respondents expressing neutrality—indicative of either sporadic outreach or limited trust in extension agents. Finally, 59% of respondents either disagreed or remained neutral regarding the clarity of loan terms and conditions, suggesting communication gaps and possibly exploitative or overly complex contractual frameworks.

Table 4: Challenges faced by Farmers in accesing Agro-credit

S/N	Items	SA (%)	A (%)	N (%)	D (%)	SD (%)	x̄
1	I find it difficult to meet collateral requirements for credit	25.0	75.0	-	-	-	1.8
2	Interest rates on loans are too high	14.0	40.0	26.0	20.0	-	2.3
3	There is a lack of information on available credit facilities	26.0	27.0	34.0	13.0	-	2.4
4	The process of obtaining credit is too lengthy and complicated	27.0	59.0	14.0	-	-	2.1
5	I have limited access to financial institutions in my area	11.0	41.0	12.0	16.0	20.0	2.5
6	The documentation for credit applications is too tedious	28.0	46.0	26.0	-	-	2.2
7	There is a lack of trust between farmers and financial institutions	13.0	30.0	46.0	11.0	-	2.4
8	My previous credit history affects my current access to credit	-	38.0	22.0	40.0	-	2.0
9	Credit facilities are not tailored to the needs of maize farmers	45.0	26.0	27.0	-	-	2.6
10	There is a lack of flexibility in credit repayment schedules	34.0	12.0	41.0	13.0	-	2.2
11	I have faced discrimination when applying for credit	26.0	63.0	11.0	-	-	2.6
12	Financial literacy programs are insufficient	14.0	53.0	20.0	13.0	-	2.2
13	Loan amounts are inadequate for my farming needs	39.0	46.0	15.0	-	-	2.6
14	There is insufficient support from extension services for credit	14.0	13.0	71.0	2.0	-	2.1
15	The terms and conditions of credit are not clearly explained	13.0	28.0	28.0	31.0	-	2.2

Source: Field Survey, 2024

Conclusion

This study offers critical insights into the accessibility and influence of agricultural credit on maize production within Bida Local Government Area. The demographic characteristics of the respondents predominantly male, middle-aged individuals with varied educational attainments reflect the heterogeneity of the local farming population. The results reveal a relatively high level of awareness regarding available sources of agricultural credit, with formal financial institutions, particularly banks, serving as the primary access points. However, access is often constrained by stringent collateral requirements and the perceived unaffordability of interest rates.

Although agricultural credit has had a demonstrable positive effect on both maize output and household income levels, its overall impact is mitigated by persistent challenges. These include limited proximity to or availability of financial institutions, inadequate training and extension services related to credit application procedures, and the continued reliance on informal lending mechanisms. These findings are consistent with existing empirical evidence underscoring the importance of accessible, affordable, and well-structured credit systems in fostering agricultural development. Consequently, mitigating the identified constraints is essential for enhancing the economic resilience and productivity of smallholder maize farmers in Bida LGA.

5.3 Recommendations

In light of the study's findings, the following policy and institutional recommendations are proposed to improve the accessibility and effectiveness of agricultural credit for maize farmers in Bida Local Government Area:

1. Improve Credit Accessibility: Financial institutions should streamline credit application procedures by minimizing collateral requirements and offering more transparent and competitive interest rates. Expanding the geographical reach of these institutions into rural farming communities is essential for reducing physical barriers to access.
2. Enhance Farmer Awareness and Capacity Building :Targeted training programs should be developed to enhance farmers' financial literacy, particularly regarding available credit sources, application procedures, and credit management. Improved knowledge will enable farmers to make more informed and strategic financial decisions.
3. Strengthen Government and Cooperative Credit Mechanisms :Government-led agricultural financing schemes and farmer cooperatives should be reinforced and better integrated into the rural finance ecosystem. Partnerships with local institutions can improve credit delivery and provide farmers with tailored support services.
4. Support Community-Based Credit Initiatives :The promotion of local, community-based lending models such as rotating savings and credit associations (ROSCAs) and cooperative lending groups can serve as viable alternatives to formal finance, offering flexible terms and greater accessibility.
5. Establish Monitoring and Feedback Mechanisms :A structured framework for the regular evaluation of credit programs should be instituted. Continuous monitoring and incorporation of farmer feedback will help identify systemic challenges and inform data-driven improvements to credit delivery systems.

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TECHNOLOGY FOR SUSTAINABLE CONCRETE

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ABSTRACT
Growing concerns about global warming and major ecological changes necessitate sustainable growth across all scientific and technological domains. Concrete not only uses a lot of natural resources and energy, but it also releases a lot of carbon dioxide, mostly from the cement manufacturing process. The energy, resource, environment, and ecology of civilization have all been significantly impacted by the massive production of concrete. Therefore, a major concern now is how to improve concrete technology in a sustainable manner. This paper presents a few Korean studies on the sustainable development of concrete. These include adding recycled aggregate and additional cementing elements to concrete, strengthening deteriorating concrete structures, reinforcing new concrete structures sustainably, and applying each approach to recast concrete.
Keywords: Recycled aggregate, industrial by-product, FRP reinforcement, sustainable development.

Introduction

Sustainable development is the organizing principle for sustaining finite resources necessary to provide for the needs of future generations of life on the earth. It is a process that envisions a desirable future state for human societies in which living conditions and resource-use continue to meet human needs with out undermining the "integrity, stability and beauty" of natural biotic systems. The 1987 Brundtland Report is where the idea of sustainable development is most strongly derived.The United Nations World Commission on Environment and Development published the Brundtland Report, often known as "Our Common Future," in 1987.One of the most well-known definitions of sustainable development was contained in this study . As seen in Figures 1 and 2, cement production has been rising steadily [2].One of the main sources of greenhouse gas emissions is the manufacture of cement. Therefore, the concrete industry has a big influence on our planet's ecology. Even in Korea, the question of how to develop concrete technology sustainably has become a pressing global concern.One of the main causes of global climate change is greenhouse gasses.In 2014, Korea was the ninth-largest emitter of greenhouse gases, accounting for 1.75% of worldwide CO2 emissions as illustrated in Figure 3 [3].

The expansion of the service life of concrete structures and the creation of low-carbon concrete materials and structures are currently the focus of research on sustainable development of concrete.Therefore, the following three categories—strengthening technique of existing concrete structure, sustainable concrete, and sustainable reinforcement—are used in this study to present some sustainable concrete technologies that have advanced in Korea.

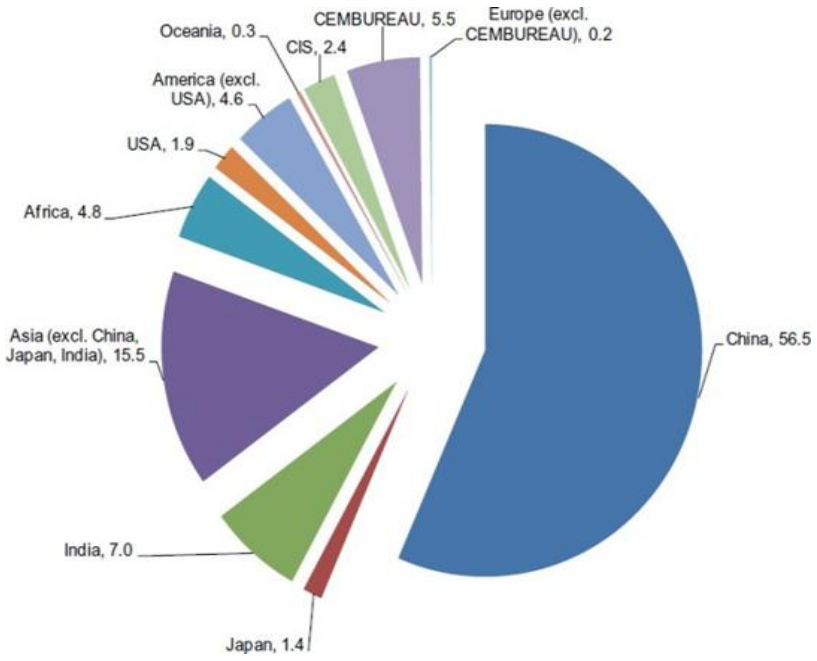


Figure 1. WorldCementProduction2014, byRegionand Main Countries (%) [2]

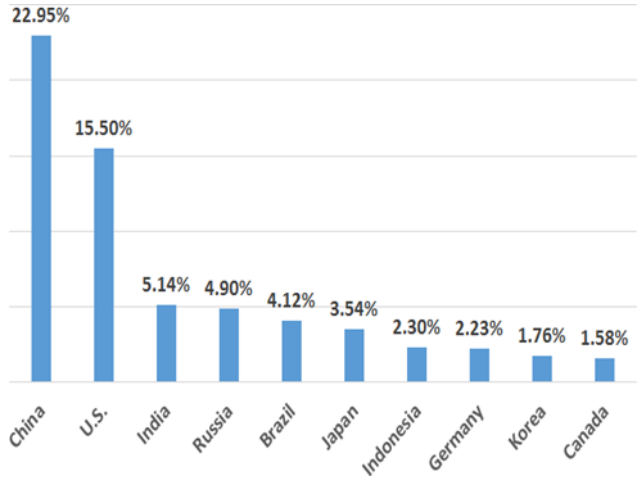


Figure2. The10LargestCO2Emitters2014[3]

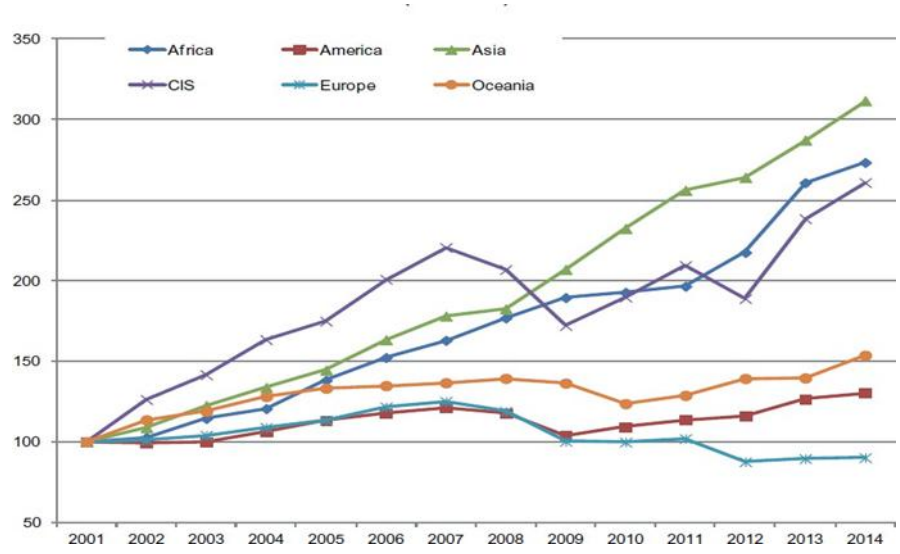


Figure3. WorldCementProductionbyRegion–Evolution2001~2014(index:2001=100)[2]

1.Method for Reinforcing the Current Concrete Structure

A concrete structure's deterioration due to age or damage results in a drop in durability and performance. For deteriorated concrete structures to remain safe and serviceable, they must bestrengthened, restored, rebuilt, or demolished. One method to increase a concrete structure's service life with the least amount of negative environmental, social, and economic repercussions is to fortify it. Steel plate has been widely employed as a traditional reinforcing material for concrete structures. However, steel has shown weakness as a strengthening material because of its increasing self-weight, corrosion, and applicability limit. Consequently, the use of FRP (Fiber Reinforced Polymer) is growing in strength. These days, it's because of the benefits of FRP, which include its high tensile strength, resistance to corrosion, and lightweight nature. Strengthening techniques using FRP and steel are shown in Figure 4.

Figure4. StrengtheningofConcreteStructurewithSteel andFRP

2.Sustainable Concrete

The volume of construction debris has significantly increased over the past ten years as a result of the demolition of older structures, building reconstruction, raising living standards, etc. Additionally, natural aggregate supplies for building are quickly running out. As a result, social and environmental demands on building waste make recycling the waste more important. Recycled concrete aggregate (RCA) has occasionally been used sparingly and only for low-value applications like road base materials. Concrete engineers' poor understanding of the quality and performance of RCA and concrete employing RCA, as well as the inconsistent supply of trash to their recycling plants, which results in unpredictable deliveries of finished RCA, may be the main causes. In the past, the recycling method was insufficient to generate an RCA of high quality with the right amount of economic efficiency. However, the recycling process to create RCA with a quality that is comparable to natural aggregate demonstrated to provide high-quality recycled aggregate, such as (1) mechanical grinding, as seen in Figure (8) heating and grinding (Figure 9), and (3) acid treatment [17]. This paper presents a study on recycled aggregate that has been treated with acid.

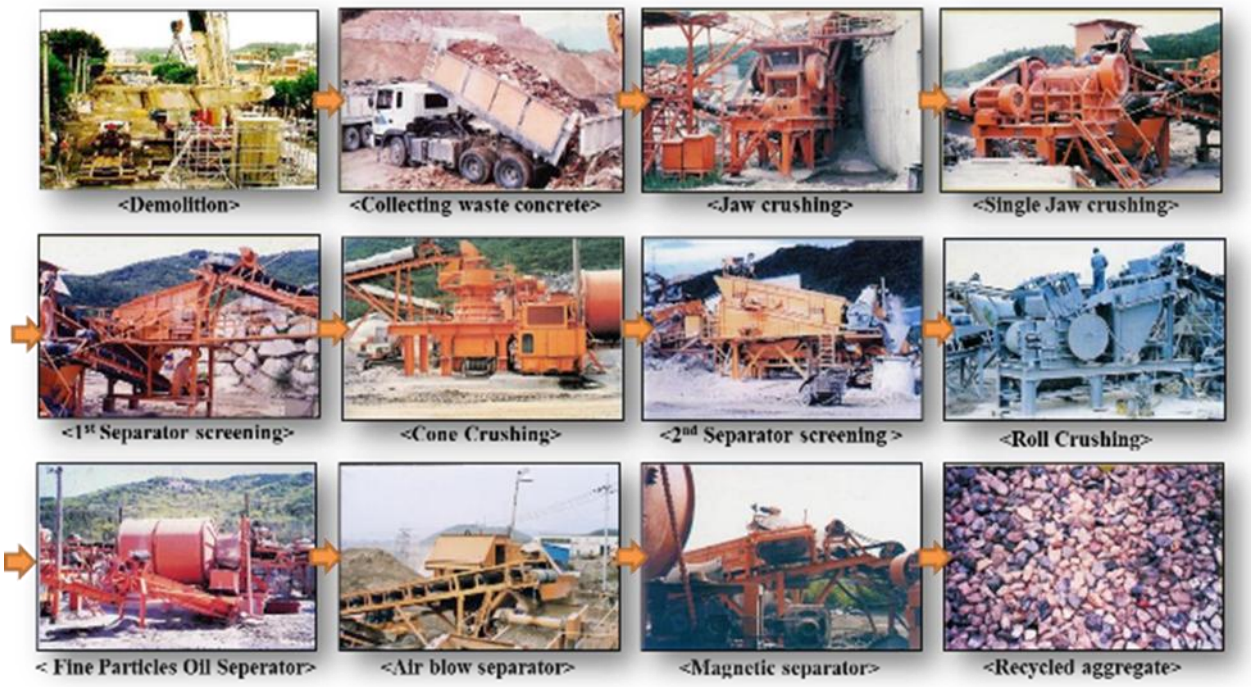


Figure8.Production Process of Recycled Aggregate

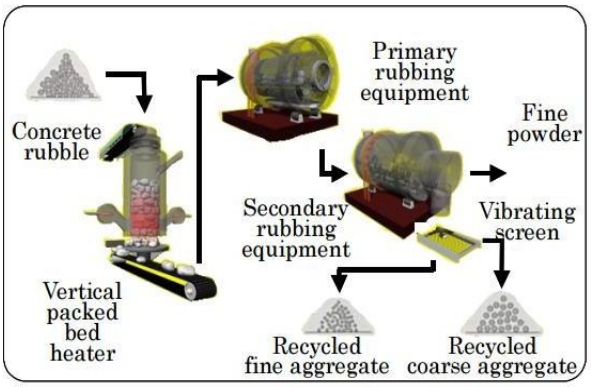


Figure9. Process of Aggregate Refining by Heating and Grinding Method

3.Recycled Aggregate with Acid Treatment

Natural aggregate was utilized to create the control mix. In addition to well-graded natural fine aggregate, the maximum size of natural coarse aggregate was 25 mm. The same conditions that applied to natural aggregates also applied to recycled aggregates. However, recycled aggregates contained contaminants such as glued mortar. Thus, it was suggested that the bonded mortar be removed using acid (HCl) treatments in order to examine the strength.

According to the results of the compression test, the concrete specimens' compressive strength is trending upward in their early years. But it demonstrates that strength.
Compared to native aggregate specimens, recycled aggregate specimens are slower. The main element that degrades the mechanical behavior of concrete is the cement and mortar that are affixed to the recycled material. Therefore, in order to improve their quality, connected mortaria must be removed. A graphical illustration of the variation in compressive strength decreasing for each batch that was analyzed is shown in Figure 10. The primary reason for the lower quality of recycled concrete is the bonded mortar content, which produced porous, highly absorbent concrete and fissures when the concrete waste was crushed. In this work, various concentrations of hydrochloric acid have been employed to successfully remove the bound mortar component. It demonstrates that the RCA's water absorption has significantly decreased

4. Long-Term Reinforcement

Traditional concrete constructions with steel reinforcing bars inevitably deteriorate over time due to external loading or harsh environmental factors like freeze-thaw cycles, alkali reactions, and de-icing salt. When reinforced concrete members deteriorate, it can result in more severe structural damage and ultimately structural failure. Reinforcing materials that do not corrode are the most effective technique to avoid corrosion . To address the fundamental issues with steel rebar, numerous studies have concentrated on creating new reinforcing materials, such as fiber-reinforced polymers (FRPs) .FRP rebar is often made of inorganic fibers like a ramid fiber or organic fibers like carbon and glass fiber that are linked together with polymers like polyester, vinyl-ester, or epoxy in reinforced concrete construction. Because of its many qualities and affordability, glass fiber reinforced polymer (GFRP) makes up the bulk of FRP/polymer matrix composites.

Commercial GFRP rebar is made utilizing a pultrusion technique, which is appropriate for the construction sector because to its high quality, quick operation, and reasonably low equipment cost.GFRPrebar, on the other hand, has a simple surface and is simply pultruded. It won't be able to form a strong enough connection to reinforce concrete structures. Therefore,

the surface structures of GFRP rebar that are utilized to improve bonding with concrete are often divided into three groups:sand-coated, braided, or deformed patterns.

5. Comparing FRPRebars using the Pull-out Test

This pull-out test is intended to assess the proposed GFRP rebar's bonding capacity with 50% milled glass fibers and to compare it to other bar types. The rebars tested here have a median diameter that is roughly the same as that of No. 3 steel rebar. The examples are named for their surface patterns: the surface-braided GFRP rebar [SBR], whose surface is braided with glass fibers; the sand-coated GFRP rebar [SCR]; and the projected deformed GFRP rebar [PDGR]. Additionally, a regular steel rebar with. The mechanical characteristics of the rebars utilized in pull-out tests are described in Table 1.In MPa, the bond strength (σb) was computed.

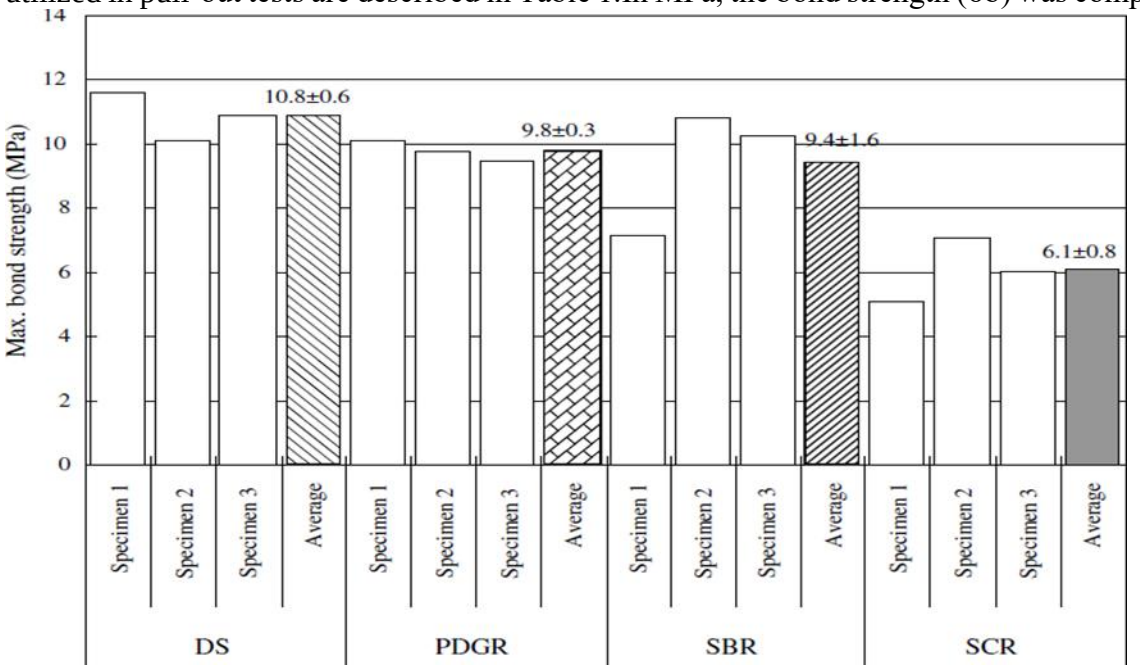
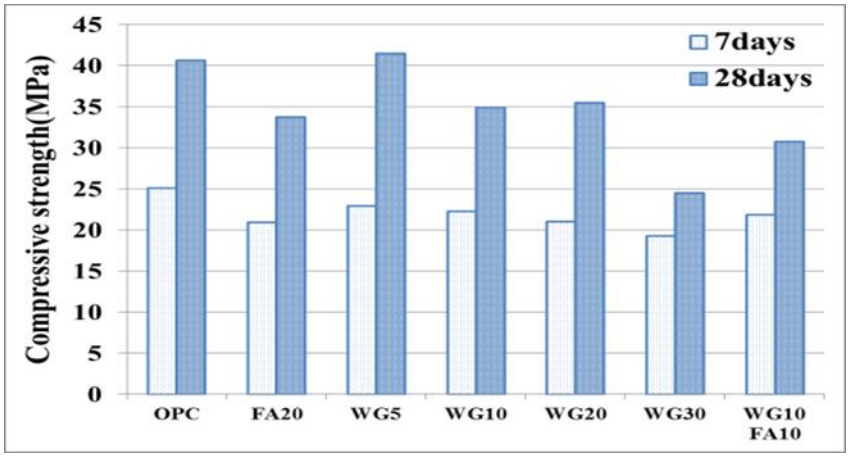
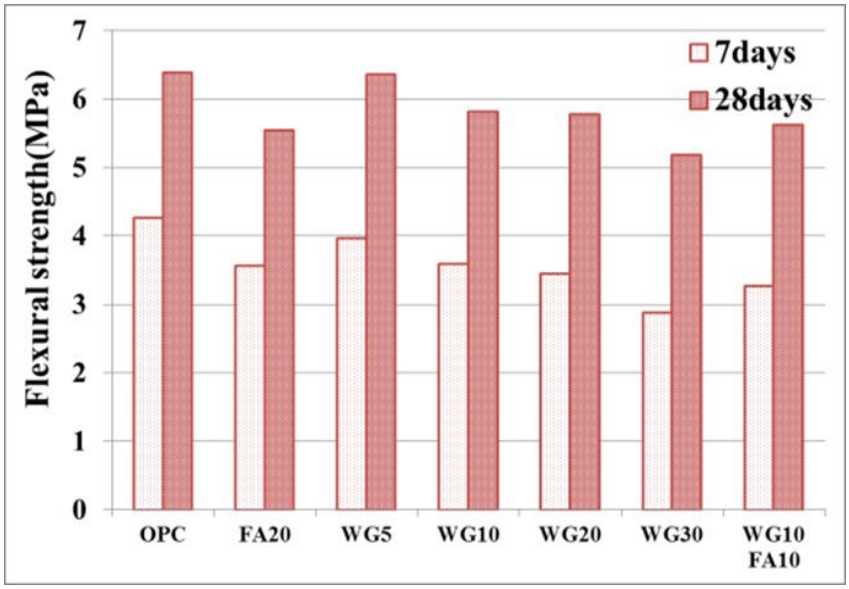


Table1. SummaryandMechanicalPropertiesofBarsin Pull-outTest

Anexampleofa columnheading	Nominaldiameter	Ultimatestrength	Elastic modulus (MPa)
DS	9.5	660	200
PDGR	10.3	592	44.5
SBR	10.7	910	53.5
SCR	10.3	1000	34.8





Summary

Scientific approaches for the sustainable development of concrete in Korea have been introduced in this research in the following ways: • Appropriately strengthening damaged concrete structures with FRP,
• Recycling building debris into fine and coarse aggregate using sophisticated production techniques,

The use of industrial by-products as additional cementing materials and the fundamental use of FRP rebar to prevent reinforcement corrosion and Precast concrete could use these technologies to seek sustainable concrete development. Precast concrete with recycled aggregate has the advantages of lowering production costs and raising awareness of the use of recycled material in concrete. Additionally, using industrial by-product to precast concrete . The findings of these studies have aided in the sustainable development of infrastructure and concrete materials, and more research on their sustainable development aspects is positively required.

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ANDEZİT TOZU VE TUĞLA TOZUNUN ÇİMENTO İKAME MALZEMESİ OLARAK KULLANIMI

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ÖZET

Betona olan gereksinim nüfus artışı ile birlikte her geçen gün artmaktadır. Bu durum betonu en popüler yapı malzemesi konumuna getirmektedir. Farklı özelliklerde sayısız beton türü bulunmakla birlikte çimentosuz beton üretimi, sürdürülebilirlik açısından halen soru işaretleri oluşturmaktadır. Bu yüzden günümüzde en yaygın kullanılan beton bağlayıcı malzemesi çimentodur. Bununla birlikte çimentonun betonun dayanım ve dayanıklılık gibi performans özelliklerini olumlu yönde etkilediği bilinmesine rağmen, çevresel etkilerinden dolayı dezavantajlı olduğu da unutulmamalıdır. Özellikle çimento ana hammaddesi olan klinker üretimi sürecinde atmosfere önemli miktarda karbon dioksit (CO_2) salınımı gerçekleşir. Bu durum atmosferin kirlenmesine yol açarak çevre kirliliğine neden olur. CO_2 salınımını ve karbon ayak izini azaltmanın en etkili yolu ise klinker yerine kısmen alternatif hammaddelerin kullanılmasıdır. Bu amaçla, çalışmada; andezit tozu (AT) ve tuğla tozu (TT) ikameli çimento harçlarının kimyasal, fiziksel ve mekanik özellikleri araştırılmıştır. Çalışmanın ilk aşamasında; CEM I 42.5 R tipi çimento (PÇ), AT ve TT tanelerinin kimyasal ve fiziksel özellikleri belirlenmiştir. İkinci aşamada; referans, %2.5AT+%2.5TT, %5AT+%5TT, %7.5AT+%7.5TT ve %10AT+%10TT ikameli harç numunelerinin; su ihtiyaçları, genleşme değerleri ve priz süreleri belirlenmiştir. Çalışmanın son aşamasında ise; numunelerinin 7 ve 28 günlük eğilme ve basınç dayanımı değerleri belirlenmiştir. Çalışmanın sonucunda, ilgili standartlar çerçevesinde PÇ yerine %20 oranına kadar AT ve TT'nun (10A10T) ikame edilebileceği tespit edilmiştir.

Anahtar Kelimeler: Andezit tozu (AT), tuğla tozu (TT), ikameli çimento.

USE OF ANDESITE POWDER AND BRICK POWDER AS CEMENT REPLACEMENT MATERIALS

ABSTRACT

The demand for concrete is increasing daily with the rise in population, making it the most popular construction material. Although there are numerous types of concrete with varying properties, the production of cement-free concrete still raises concerns in terms of sustainability. Therefore, cement remains the most widely used binder material in concrete today. While it is well known that cement positively influences the strength and durability properties of concrete, its environmental impact cannot be overlooked. In particular, the production of clinker, the primary raw material of cement, releases a significant amount of carbon dioxide (CO_2) into the atmosphere. This contributes to air pollution and environmental degradation. The most effective way to reduce CO_2 emissions and the carbon footprint is to partially replace clinker with alternative raw materials. In this study, the chemical, physical, and mechanical properties of cement mortars incorporating andesite powder (AP) and brick powder (BP) as partial replacements were investigated. In the first phase of the study, the chemical and physical properties of CEM I 42.5 R cement (PC), AP, and BP particles were determined. In the second phase, the water demand, expansion values, and setting times of the reference and modified mortar specimens containing 2.5%AP+2.5%BP, 5%AP+5%BP, 7.5%AP+7.5%BP, and 10%AP+10%BP were evaluated. In the final phase, the flexural and compressive strengths of the specimens were measured at 7 and 28 days. The results indicated that, within the relevant standards, up to 20% of PC could be replaced with AP and BP (10A10T) without compromising performance.

Keywords: Andesite powder (AP), brick powder (BP), partial replacement cement.

1.GİRİŞ

Çimento, dünyanın birçok ülkesinde üretilen ve en çok kullanılan yapı malzemesidir. Saf çimento olarak bilinen CEM I Portland çimentosunun içeriğinde %95 - %100 aralığında klinker bulunmaktadır ve özellikle klinker üretimi aşamasında açığa çıkan CO_2 gazı, küresel ısınmaya ve dolayısıyla atmosferin kirlenmesine sebep olmaktadır (Alex, Dhanalakshmi, and Ambedkar 2016; Westgate, Ball, and Paine 2019). Bu sebepten dolayı araştırmacıların çimento ikame malzemesi üzerine arayışları hızla devam etmektedir (Ma et al. 2020; Tuyan 2019; Vouk et al. 2018). Çimento endüstrisinde uçucu kül, yüksek fırın cürufu, silis dumanı gibi mineral katkıların kullanıldığı bilinmektedir. Özellikle son yıllarda çimento harcı içerisinde farklı malzemelerin kullanılabilirliğinin araştırıldığı güncel birçok çalışma yapılmıştır (Altunci and Öcal 2021; Ankur and Singh 2021; Cho, Jung, and Choi 2019; Jueyendah et al. 2021; Kocak 2020; Kocak and Nas 2014; Kocak, Tasci, and Kaya 2013; Kurtay, Gerengi, and Kocak 2020; Nasr et al. 2020; Özkan and Ceylan 2022; Pınarcı and Kocak 2022; Raheem, Abdulwahab, and Kareem 2021; Zhang et al. 2021).

Andezit tozu (AT) ve tuğla tozu da (TT) çimento ikame malzemesi olarak araştırılan atıklardandır. Soykan, Cengiz, and Cenk (2015), AT'nun beton agregası olarak kullanılabileceğini belirlemişlerdir. Çelikten and Canbaz (2021), çimento yerine ağırlıkça %15 AT ikame oranının en uygun oran olduğunu tespit etmişlerdir. Ceylan and Davraz (2019), C40/50 dayanım sınıfı için, 28 ve 90 günlük kür yaşlarında AT'nin en uygun yer değiştirme oranını %10 olarak belirlemişlerdir. Tuyan (2019), kendiliğinden yerleşen beton (KYB) içerisinde çimento yerine %15 TT'nun basınç dayanımı açısından en uygun oran olduğunu, ancak KYB içerinde TT kullanımının işlenebilirlik ve geçirimlilik özelliklerini olumsuz etkilediğini tespit etmiştir. Özgan and Yıldız (2009), %5 katkılı krom magnezit TT'nun çimentoda priz başlama ve bitiş sürelerini kısmen azalttığını ancak TT miktarı arttıkça priz başlama ve bitiş sürelerinin uzadığını belirlemişlerdir.

Bu bağlamda çalışmada, AT ve TT ikameli çimento harçlarının kimyasal, fiziksel ve mekanik özelliklerinin araştırılması amaçlanmıştır. Çalışmanın ilk aşamasında PÇ, AT ve TT'nun kimyasal ve fiziksel özellikleri belirlenmiştir. İkinci aşamada %0 referans, ağırlıkça %2.5AT+%2.5TT, %5AT+%5TT, %7.5AT+%7.5TT ve %10AT + %10TT olmak üzere 5 farklı tip çimento için üretimler yapılarak, su ihtiyacı, genleşme ve priz süresi deneyleri yapılmıştır. Çalışmanın son aşamasında ise; AT ve TT ikameli harç numunelerinin 7 ve 28 günlük eğilme ve basınç dayanımı değerleri belirlenmiştir.

2.MATERYAL ve METOT

2.1.Materyal

Deneysel çalışmada kullanılan materyaller; Isparta Göltaş Çimento fabrikasından temin edilen PÇ, Isparta/Türkiye bölgesinden temin edilen AT, Burdur/Türkiye bölgesinden temin edilen TT, CEN standart kum ve Isparta ili şebeke suyudur.

2.2.Metot

Çalışma kapsamında; ilk olarak PÇ, AT ve TT'nun kimyasal ve fiziksel özellikleri belirlenmiştir. Kimyasal ve fiziksel analizlerden sonra, deneylerde kullanılmak üzere %0 referans, ağırlıkça %2.5AT+%2.5TT, %5AT+%5TT, %7.5AT+%7.5TT ve %10AT+%10TT olmak üzere 5 farklı tip çimento hazırlanmıştır. AT ve TT ikameli çimento harç numuneleri bir birim çimento ve üç birim kum olacak şekilde TS EN 196-1 standardına göre üretilmiştir. AT ve TT ikameli çimento harç numunelerine ait notasyon ve karışım miktarları Tablo 1'de verilmiştir.

Tablo 1. AT ve TT ikameli çimento harç numunelerine ait notasyon ve karışım miktarları

Notasyon	İkame oranı (%)	Çimento (g)	Andezit tozu (g)	Tuğla tozu (g)	Su (g)	Kum (g)
0A0T	0	450,00	0	0		
2.5A2.5T	2.5AT + 2.5TT	427,50	11,25	11,25		
5A5T	5AT + 5TT	405,00	22,50	22,50	225,00	1350,00
7.5A7.5T	7.5AT + 7.5TT	382,50	33,75	33,75		
10A10T	10AT + 10TT	360,00	45,00	45,00		

AT ve TT ikameli çimento numunelerinin; su ihtiyaçları, genleşme değerleri ve priz süreleri TS EN 196-3 standardına göre belirlenmiştir. Daha sonra TS EN 196-1 standardına göre üretilen AT ve TT ikameli çimento harçları, her numune grubu için 40×40×160 mm boyutlarındaki üçlü prizmatik kalıplara alınarak vibrasyon uygulamasına tabi tutulduktan sonra bir gün süreyle kalıpta bekletilmiş ve daha sonra kalıplarından çıkartılarak kür havuzuna konulmuştur. 7 ve 28 günlük kür süresinden sonra AT ve TT ikameli harç numunelerinin eğilme ve basınç dayanımı değerleri belirlenmiştir.

3.BULGULAR ve TARTIŞMA

3.1.Kullanılan Malzemelerin Kimyasal ve Fiziksel Özellikleri

AT ve TT'u 63 µ'luk elekten elenerek kullanılmıştır. PÇ, AT ve TT'ye ait kimyasal ve fiziksel analiz sonuçları ise Tablo 2'de verilmiştir.

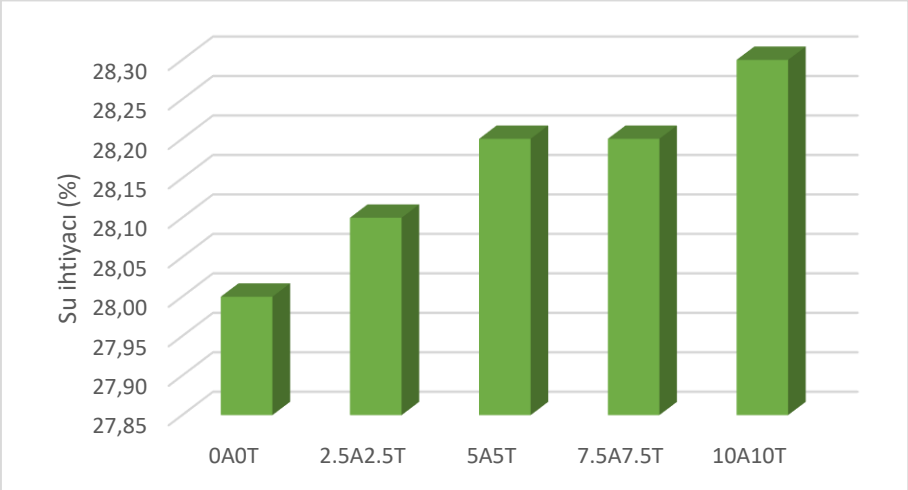
Tablo 2. PÇ, AT ve TT'ye ait kimyasal ve fiziksel özellikler

		CEM I 42.5 R	Andezit tozu	Tuğla tozu
CaO		63,55	5,02	12,13
SiO_2		20,31	57,01	49,45
Al_2O_3		4,54	17,26	14,05
Fe_2O_3		3,47	5,67	6,89
K_2O	**(%)**	0,80	2,89	2,03
Na_2O		0,87	3,84	1,51
MgO		1,51	1,79	7,00
TiO_2		-	0,49	0,59
SO_3		2,75	0,21	1,63
Kızdırma kaybı	**(%)**	2,80	3,40	4,56
Özgül ağırlık	**(g/cm^3)**	3,12	2,71	268
Özgül yüzey	**(cm^2/g)**	3130	5800	5100

Tablo 2'ye göre SiO_2 + Al_2O_3 + Fe_2O_3 toplamı AT için %79,94 ve TT için ise %70,39'dur. Bu değerler her iki atık toz için, PÇ bünyesindeki üç majör oksitin toplamının yaklaşık iki katı kadardır. AT ve TT bünyesindeki üç majör oksit oranının %70'i geçmiş olması ve kızdırma kaybı değerinin de %5'in altında olması ASTM C618-22 (2023)'e göre hem AT'nun hem de TT'nun F sınıfı uçucu kül sınır değerini sağladığını ve her iki atık tozunda TS EN 450-1 (2013)'e göre puzolan olarak sınıflandırıldığını göstermektedir.

3.2.Su İhtiyacı

AT ve TT ikameli çimento harçlarının su ihtiyacı yüzdeleri, TS EN 196-3 (2017), standardına uygun olarak belirlenerek Şekil 1'de verilmiştir.

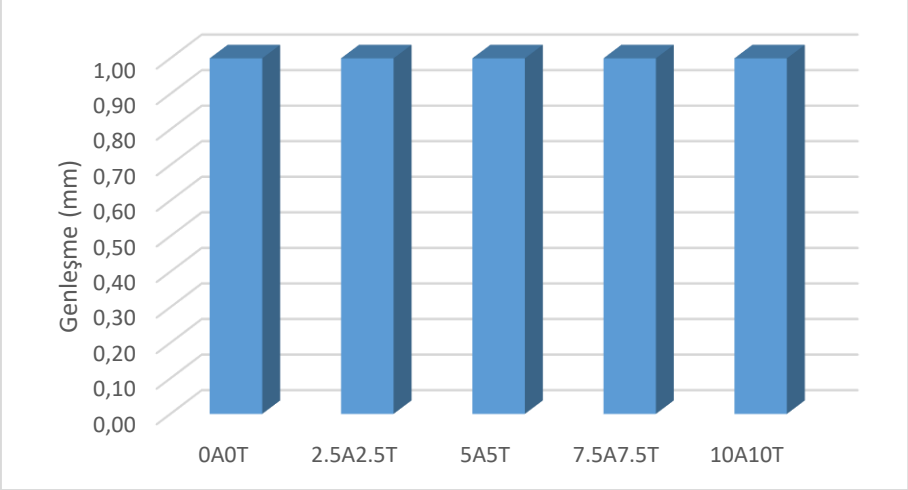


Şekil 1. AT ve TT ikameli çimento harçlarının su ihtiyaçları

Şekil 1'e göre, ikame oranı artışı ile birlikte su ihtiyacının az da olsa arttığı görülmektedir. Bu durum, AT ve TT'u ikamesinin işlenebilirliği arttırmasına bağlı olarak, şahit numuneye göre özdeş kıvamı yakalama durumuyla açıklanabilir (Koçak 2011). 0A0T şahit numunesi ile %20 ikameli 10A10T numunesi arasındaki su ihtiyacı farkının az olması (%0,30) su/çimento oranını fazla arttırmadan referans kıvamın elde edilebileceğini göstermektedir.

3.3.Genleşme Değerleri

AT ve TT ikameli çimento harçlarının genleşme değerleri, TS EN 196-3 (2017), standardına uygun olarak belirlenerek Şekil 2'de verilmiştir.

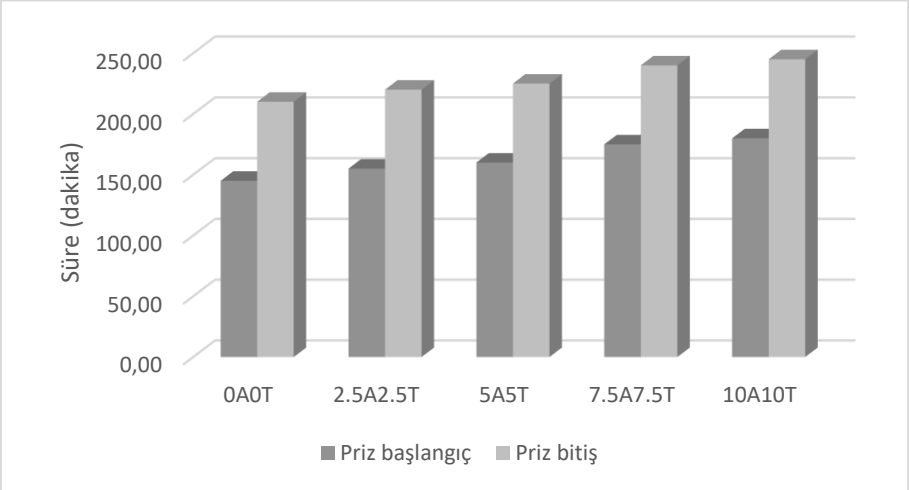


Şekil 2. AT ve TT ikameli çimento harçlarının genleşme değerleri

Şekil 2 dikkate alındığında, tüm numunelerin genleşme değerleri 1mm olarak bulunmuştur. Bu durum AT ve TT'nun kimyasal yapısında bulunan ve fazlalığı genleşmeye neden olan, Magnezyum Oksit (MgO) ve Kalsiyum Oksit (CaO) içeriğinin sınır değerler içerisinde kaldığını göstermektedir (Çelikten and Canbaz 2021; Ceylan and Davraz 2019).

3.4.Priz Süreleri

AT ve TT ikameli çimento harçlarının priz süreleri, TS EN 196-3 (2017), standardına uygun olarak belirlenerek Şekil 3'de verilmiştir.

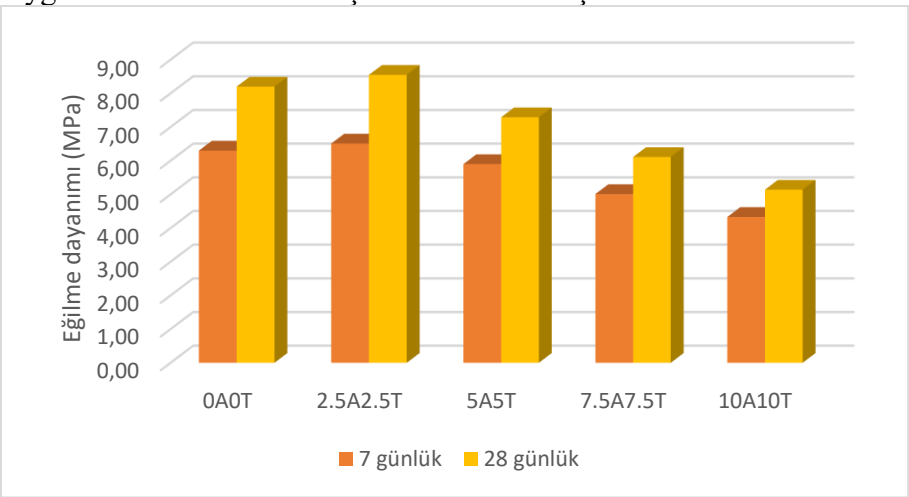


Şekil 3. AT ve TT ikameli çimento harçlarının priz süreleri

Şekil 3'de görüldüğü üzere, ikame oranı artışı ile birlikte, priz başlangıç ve priz bitiş sürelerinde artış söz konusudur. AT ve TT'nun PÇ'ya göre nispeten daha yüksek özgül yüzey alanına sahip olması, numunelerin priz sürelerini uzatmıştır.

3.5.Eğilme Dayanımı

AT ve TT ikameli çimento harçlarının eğilme dayanımları, TS EN 196-1 (2016), standardına uygun olarak belirlenerek Şekil 4'de verilmiştir.

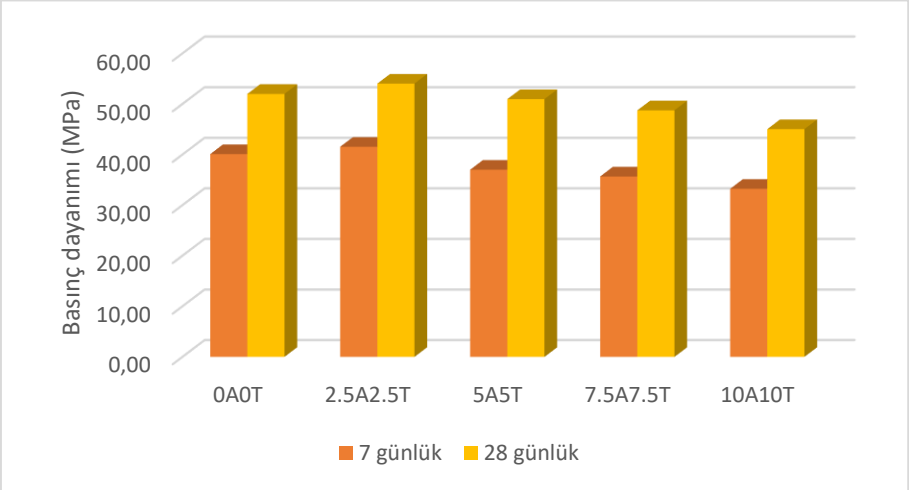


Şekil 4. AT ve TT ikameli çimento harçlarının eğilme dayanımı değerleri

Eğilme dayanımı deney sonuçları incelendiğinde, 2.5A2.5T numunesinin referans numuneye göre 7 gün için %3,33 ve 28 gün için %4,27 oranında daha iyi performans gösterdiği belirlenmiştir. Ayrıca %5 ikame oranından sonraki her ikame oranı için hem 7 hem de 28 günlük eğilme dayanım değerlerinin referans numuneye göre azaldığı görülmüştür. 2.5A2.5T numunesindeki AT ve TT'nun mikro boşlukları doldurarak az da olsa eğilme dayanımı artışına neden olduğu; %5 ikame oranından sonra ise Kalsiyum Silika Hidrat (C-S-H) jeli oluşturmada yetersiz kaldığı söylenebilir.

3.6.Basınç Dayanımı

AT ve TT ikameli çimento harçlarının basınç dayanımları, TS EN 196-1 (2016), standardına uygun olarak belirlenerek Şekil 5'de verilmiştir.



Şekil 5. AT ve TT ikameli çimento harçlarının basınç dayanımı değerleri

Yapılan deney sonuçlarına göre, en düşük basınç dayanım değerleri 10A10T numunesinde (7 günlük 33,24 MPa ve 28 günlük 45,03 MPa) ölçülmüştür. En yüksek basınç dayanım değerleri ise 2.5A2.5T numunesinde (7 günlük 41,55 MPa ve 28 günlük 54,13 MPa) ölçülmüştür. Basınç dayanımının 2.5A2.5T numunesinde artması, AT ve TT'nun mikro boşlukları doldurmasıyla açıklanabilirken; 5A5T numunesinden itibaren dayanımın azalmaya başlaması, AT ve TT'nun puzolanik özellikleri nedeniyle hidratasyon reaksiyon hızını azaltmasından kaynaklandığı düşünülmektedir.

4.SONUÇ

Yapılan deneyler sonucunda elde edilen bilgiler aşağıdaki özetlenmiştir.

- Tüm numenlerin TS EN 197-1 (2012) standardında belirtilen 28 günlük sınır basınç dayanımı değerini ve TS EN 196-3 (2017) standardında belirtilen genleşme ve priz süresi sınır değerlerini sağladığı belirlenmiştir.
- 2.5A2.5T numunesi, 7 ve 28 günlük dayanım değerleri açısından en iyi performansı göstermiştir.
- 5A5T ve 7.5A7.5T numuneleri, 28 günlük dayanımıyla öne çıkmaktadır.
- 10A10T numunesinin, ekonomiklik gerektiren yerlerde kullanılması uygundur.

Sonuç olarak, AT ve TT'nun PÇ yerine %20 ikame oranına kadar kullanılmasında herhangi bir sakınca yoktur. Bunun yanında, bundan sonraki çalışmalarda DTA-TG, FT-IR, XRD, SEM gibi modern tekniklerin kullanılmasının faydalı olacağı düşünülmektedir.

Teşekkür

Yazar, deneylerin yapılmasında katkı sağlayan Isparta GÖLTAŞ Çimento Fabrikası'na teşekkür eder.

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SYNTHESIS AND CHARACTERIZATION OF METAL-METAL POLYMERIC ADHESIVES AND INVESTIGATION OF THE EFFECT OF COMPOSITE FORMS ON BONDING PERFORMANCE

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ABSTRACT

Epoxy-based adhesives play an important role in the formation of the bond between metal-to-metal components. Epoxy adhesives consist of a two-component system: epoxy resin and a hardener (usually amine or anhydride). When these two components are mixed, a chemical reaction begins and polymerization occurs, thus forming a strong bond[1]. As a result of the polymerization process, the epoxy reacts with the hardener and hardens, creating a solid bond between the metal surfaces. This bond provides maximum effect when the surfaces are clean, oil-free and properly prepared. Surface preparation is often required for the successful application of epoxy adhesives; cleaning the surfaces and applying special coatings or primers when necessary will increase bond strength and support long-term performance [2].Epoxy-based metal-to-metal adhesives are known as high-strength adhesives, often used in industrial and engineering applications[3]. Some of the key features of such adhesives are: Epoxy-based adhesives generally offer high strength and create a strong, durable and long-lasting bond between metal-to-metal components[4]. Corrosion resistance is of great importance in metal-to-metal bonding. Epoxy-based adhesives are highly durable even in corrosive environments because they are well compatible with metal surfaces. In addition, these adhesives are generally resistant to various chemicals[5]. These properties provide significant advantages in industrial environments where various chemicals are exposed. Resistance to temperature fluctuations and high temperatures is also a critical factor in metal-to-metal bonding. Epoxy-based adhesives generally have the ability to remain stable over a wide temperature range[6]. In this study, highly functional pol(GMA-co-GMS) copolymers and composites were synthesized. Single-action overlap joints (metal-metal) were prepared and their mechanical performances were investigated. Copolymers were synthesized from epoxy-containing monomers and GMS monomers with high potential for adhesion to surfaces. In addition, different types of metal oxides (alumina Al_2O_3) were added to increase the mechanical and thermal strength of the polymer. Optimization studies of the chemical, mechanical and thermal properties of these prepared composites were carried out.

Key words: Epoxy based adhesives, Adhesives, Single shear test, Polymeric composites, Metal-metal polymeric adhesives.

Introduction

There are many methods to join materials today. Some of these are welding, soldering, bolting, riveting and bonding. This study was about bonding, which is one of the methods used for joining. Today, bonding has become a frequently used method as a field of use. The biggest reason for this increase is the advantages gained by joining with bonding. The history of the first material used as an adhesive dates back to very old times. An example of this is the primitive tribes joining their broken pots with adhesive resin made from tree sap. Adhesives began to be widely used in the 1700s [7]. The most common areas of use for adhesives are adhesive joints. Adhesive joints are obtained by combining two parts with a synthetic-based material that acts as a bond in a way that will not dissolve. The adhesive, which is in the form of a very thin layer between the parts, often cures with the help of macromolecules as a result of chemical reactions [7].

Single and double overlap adhesive bonded systems are used in the industry. The quality of adhesive bonds is affected by environmental conditions, mechanical properties of the adhesive to be used, etc. In bonds where the adhesive technique is applied, the load and tension are spread over the entire bond (adhesion) surface, ensuring that all static and dynamic loads are balanced and equally distributed. Concentration at some points is prevented, and thus the strength in areas that can be considered the most dangerous points is increased. Therefore, materials made with the adhesive technique are more stable against sharpened loads than a connection made with mechanical methods. Another advantage of joining with adhesive technique is that the joint area is sealed. Thanks to this sealing, corrosion formation, which is frequently seen in joining with mechanical methods, is prevented. Parts with more than one irregular surface can be easily joined with adhesive joining technique. In recent years, there are various studies in the literature in the adhesive industry. Lee and Lee (1996) used epoxy resin as the adhesive type used in the adhesive technique and in this study, the maximum moment carrying capacity was obtained in the connections with a bonding gap of 0.05–0.15 mm. As the adhesive thickness formed due to the bonding gap increased, the moment carrying capacity decreased [8] (Ramani and Zhao 1997). The heating and cooling in the surface preparation method applied when preparing the adhesive joint, the pressure applied to the area during the entire joint process, and the time remaining at the melting and recrystallization temperature have a great effect on the strength of the joint.

The difference between the mechanical properties of the adhesive material and the bonded materials, when combined with the above-mentioned properties, causes the formation of residual stress at the adhesive-bonded material interfaces. The presence of internal stresses on the bonded surface may have various effects on the strength and sustainability of the adhesive joint [9]. (Ashcroft and Shaw, 2002) investigated the effect of temperature on fatigue crack propagation in adhesive joints of carbon fiber reinforced polymers (CFRP) bonded with epoxy adhesive (for temperatures of -50 C˚, 22 C˚ and 90 C˚) on DCB (Double-Cantilever Beam) specimens for different overlap shapes and compared the obtained results with the fracture behavior of adhesive joints under static loads and the fatigue behavior of adhesive joints without pre-cracks. As a result of the experiments, it was shown that temperature is a very effective factor in fatigue crack propagation [10]. (Ferreira et al., 2002), They investigated the effects of layer orientation, lap joint length and soaking the joints in water at different temperatures and for certain periods on the fatigue behavior of adhesive joints produced using composite materials. As a result of the experiments, it was observed that the 30 mm lap length showed better static and fatigue strength than the 60 mm lap length and they determined that the effect of water on the fatigue strength of adhesive joints depended on the water temperature and the duration of soaking the sample in water [11]. (Abdel Wahab et al., 2004), They investigated fatigue crack propagation and fatigue life in single and double lap joints using

DCB test specimens made of carbon fiber composite materials bonded with epoxy adhesive. They stated that the experimental data they obtained were in good agreement with the fatigue life prediction relations they generated using analytical and numerical methods [12].

(Kim et al., 2004) investigated the static and fatigue behavior of stepped lap adhesive joints in composite materials (carbon/epoxy) at different overlap distances, different step numbers and different edge angles. As a result of the experiments, they observed that the fatigue crack started from the last part of the overlap region and propagated between the layers [13]. (Kely, 2006) performed static and fatigue tests of the hybrid joint (bonded/bolted) that they created using CFRP composite material. Hybrid joint test specimens were manufactured in a single-action lap joint geometry and experiments were conducted for two different adhesives (epoxy, polyurethane). As a result of the experiments, it was determined that the hybrid connection showed better static and fatigue strength than the adhesive connection. The researcher modeled the experiment using the finite element method and showed that the numerical results were in good agreement with the experimental results [14]. (Quaresimin and Ricotta, 2006) investigated the effect of the overlap distance and the overlap corner geometry on the fatigue strength of the single-action overlap joints manufactured using carbon/epoxy composite material and epoxy adhesive. As a result of the experiments, the fatigue strength of the joints was higher in long overlap distances and radius corner geometry. Especially in radius corner geometry, an increase of more than 25% in fatigue strength was observed compared to the flat corner geometry [15]. (Zhai et al., 2006), they added different nanoparticles into the adhesive in the adhesive joints they created using steel material and epoxy adhesive and investigated the effect of nanoparticles on the adhesion strength of the joints. As a result of their study, they determined that especially Al2O3 nanoparticles significantly increased the adhesion strength of the joint [16].

(Zhai et al., 2007) added 2% Al_2O_3 into the adhesive in the adhesive joints they formed using steel material and epoxy adhesive and performed tensile tests. As a result of the experiments, the adhesion strength was higher in the adhesive joints reinforced with Al_2O_3 [17]. (Meneghetti et al., 2010) investigated the fatigue behavior of the adhesive joints of composite materials in the single-action lap joint test geometry they created. In their experiments, they investigated the effects of composite layer orientation, lap distance and corner geometry on the fatigue behavior in single-action lap joints. As a result, they determined that the effect of layer orientation on fatigue strength was less than the lap length and corner geometry [18]. (Srivastava, 2011), They conducted tensile tests by adding 3% multi-walled carbon nanotube reinforcement into the epoxy adhesive in the bonded joints they created using composite material and epoxy adhesive. As a result of the experiments, the static strengths of the joints using nanoparticle-reinforced epoxy adhesive were found to be higher than the joints without nanoparticle reinforcement [19]. (Reis et al., 2015) investigated the effect of loading frequency on the fatigue strength of the joints in the bonded joints they produced using steel plate and epoxy adhesive as the bonded material. As a result of the experiments, it was determined that the effect of frequency was not very important at high stress levels, while the change in loading frequency was a very important parameter at low stress levels [20].

In this study, original, innovative polymer materials were synthesized for use in adhesive applications. The products obtained were used in the bonding of metal-to-metal connections frequently used in the automotive industry.

MATERIAL AND METHOD

Synthesis of Poly(Glycidyl Methacrylate) (PGMA) (PB-0)

Azobisisobutyronitrile (AIBN) (0.0335 g) and glycidyl methacrylate (2.90 g, 3.85 mL) were dissolved in 5 mL of dry toluene solvent under argon atmosphere in a 50 mL volumetric

two necked round bottomed flask containing an oval magnetic stirrer at room temperature. The reaction flask was immersed in an oil bath at 65 °C and the reaction mixture was stirred for three hours. After the reaction was terminated by cooling at -20 °C, 5 mL of dichloromethane (DCM) solvent was added and dissolved and precipitated in 200 mL of cold methanol. PGMA was isolated by filtering through a sintered G4 filter and dried at room temperature under reduced pressure until it reached constant mass (Figure 1). The structure of PGMA was elucidated by the data obtained from FT-IR spectroscopy analysis. The FTIR spectrum of PGMA is shown in Figure 2. The signals observed between 2850-2980 cm^{-1} in the spectrum belong to aliphatic CH stretching signals. The signals observed between 830-900 cm^{-1} of the PGMA polymer in the spectrum indicate the presence of an epoxy ring in the structure.
The sharp and strong peak observed at 1731 cm^{-1} belongs to the C=O stretching signals of the ester groups in the polymer. In addition, the absence of signals belonging to alkene bonds at 1640-1680 cm^{-1} indicates that the polymerization reaction has occurred.

Homopolymer Characterization

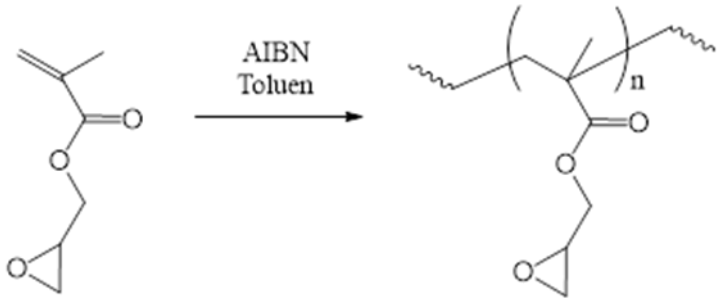

Figure 1. Synthesis of poly(GMA) homopolymers (PB-0)

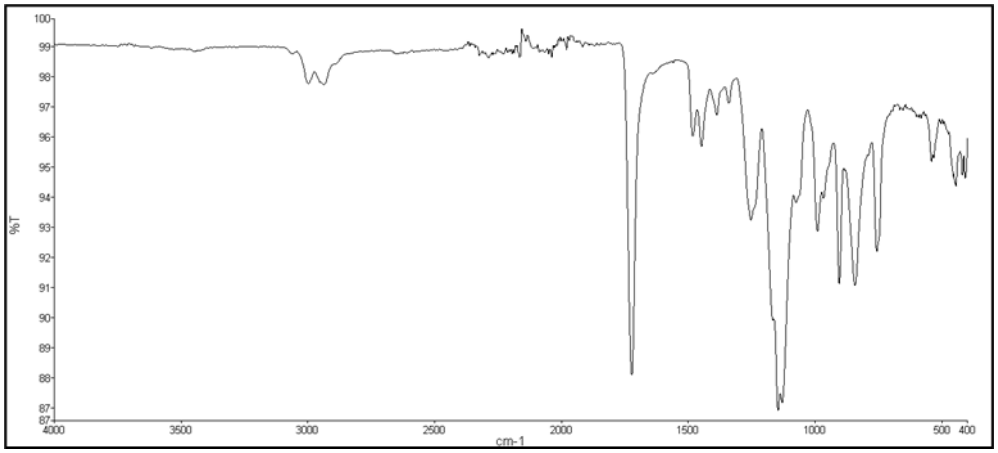

Figure 2. FTIR spectrum of PGMA.

Synthesis of PB-1, PB-2 and PB-3 Polymers and Composites and Determination of Tensile Strength by Mechanical Strength Tests

Firstly, since the GMA monomers to be used contained inhibitors, they were passed through a basic alumina column. An oval magnet was placed in a 25 mL round-bottomed flask and 1.02 mL (7.03 mmol) GMA was heated at 60 °C for 20 minutes under an argon atmosphere, then 34 mg AIBN was added as an initiator and 5 ml THF was added to initiate free radical polymerization. The reaction was copolymerized by free radical initiators known to attack double bonds. The reaction was continued in an oil bath at 60 °C and 400 rpm until the reaction was completed. After the reaction was completed, it was precipitated twice in 200 mL of cold hexane. The resulting pol(GMA) (PB-0) homopolymer was filtered in a sintered Gooch crucible and the lid was closed and left to dry in a vacuum oven for 24 hours.

Similarly, for the synthesis of copolymers at three different feed rates, oval magnets were placed in three 25 mL round-bottomed flasks and 5 mL (37.8 mmol) GMA and 15 mL (104.4 mmol) GMS; 10 mL (75.6 mmol) GMA and 15 mL (104.4 mmol) GMS; 20 mL (151.2 mmol) GMA and 15 mL (104.4 mmol) GMS monomer were added under argon atmosphere, respectively. 0.19 g of AIBN was added to the first flask, 0.07 g to the second flask, and 0.28 g to the third flask as initiator. Then, 15 mL of DMF was added to the first and second flasks, and 20 mL of DMF was added to the third flask. The first and third flasks were kept at 65 °C for 6 hours, and the second flask was kept at 65 °C for 1 hour until the reaction took on a viscous appearance. After the reaction was completed, each was precipitated twice in 200 mL of cold methanol. The upper part of the precipitated copolymers in viscous form was decanted and the mouth of the polymers remaining in the beaker was closed and left to dry in a vacuum oven for 24 hours (PB-1), (PB-2), (PB-3). The obtained polymers were used in adhesive applications both in their pure form and in composites prepared with alumina and ulexite.

Synthesized Polymers	GMA	GMS (2,3-episulfide methacrylate)	AIBN	DMF	TIME	T (°C)
PB-1 [pol(GMA(1)-co-GMS(1))]	5 mL	15 mL	0,19 g	15 mL	6h	65 °C
PB-2 [pol(GMA(2)-co-GMS(1))]	10 mL	15 mL	0,07 g	15 mL	1h	65 °C
PB-3 [pol(GMA(4)-co-GMS(1))]	20 mL	15 mL	0,28 g	20 mL	6h	65 °C

Figure 3. Synthesis of PB-1, PB-2 and PB-3 copolymers.

In order to reduce the brittleness of epoxy adhesives, we synthesized pol(GMA(1)-co-GMS(1)) (P1), pol(GMA(1)-co-GMS(2)) (P2), pol(GMA(1)-co-GMS(4)) (P3) copolymers by free radical polymerization by adding GMS monomer similar to pol(GMA) at different feed rates.

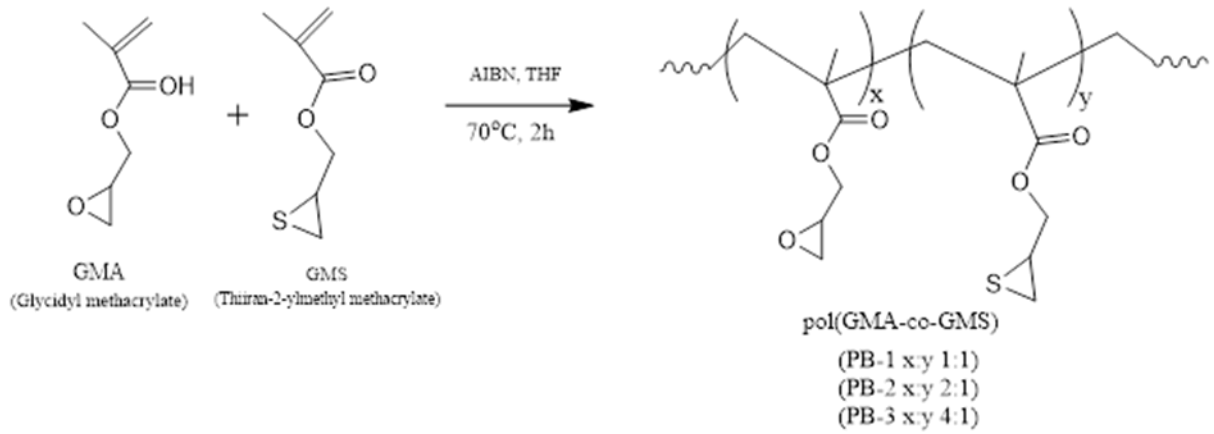

Figure 4. Synthesis of PB-1, PB-2 and PB-3 copolymer.

Copolymer Characterization

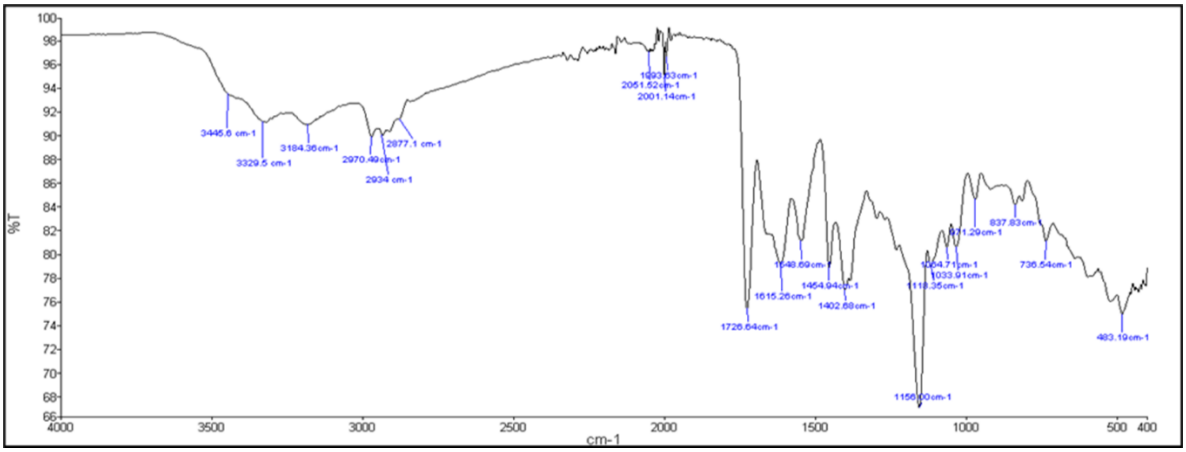

Figure 5. FT-IR spectrum of PB-1 copolymer.

The disappearance of the signals belonging to alkene bonds at 1640-1680 cm^{-1} of the PB-1 copolymer indicates that the monomers are polymerized. The signals belonging to the GMA and GMS rings seen between 830-900 cm^{-1} and 971 cm^{-1} in the spectrum indicate the presence of epoxy and episulfur rings in the structure.

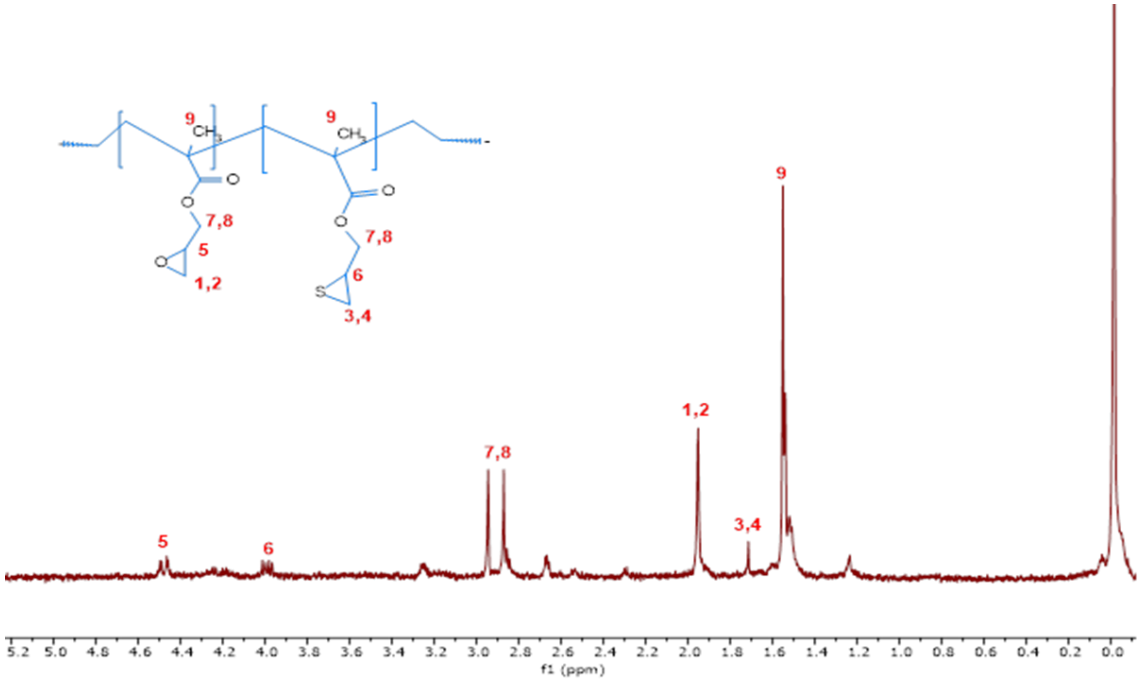

Figure 6. 1H-NMR spectrum of PB-1 copolymer.

In this spectrum, the neighboring methyl protons in the main chain resonated at 1.55 ppm. The signals of epoxy methylene protons (1,2) appeared at 1.95 and 2.00 ppm, while the signal of methylene proton (5) was observed at 4.46 ppm. Also, the methylene protons (7,8) adjacent to the epoxy ring gave signals at 2.87 and 2.94 ppm. As for the GMS side groups of the copolymer, the episulfide methylene protons in the side group (3,4) gave resonance at 1.72 ppm, while methylene protons 7 and 8 resonated at 2.87 and 2.94 ppm, respectively. The composition of the copolymer was evaluated according to the corresponding chemical displacement and the characteristic peaks were marked with the corresponding numbers in the spectrum. The disappearance of the signals of geminal protons at 5.1 and 6.08 ppm indicates that the monomer in the medium is completely consumed.

Preparation of Composite Form of p(GMA)

1g p(GMA) was dissolved in 10mL methyl ethyl ketone (MEK) in a 25mL round-bottomed flask and 0.45 mol 4 4'-methylenedianiline crosslinking agent (curer) was added for each mole of epoxy group and mixed with a magnetic stirrer. Then, calcined colemanite was added to the polymeric solution at a rate of 1-2-4% of the polymer's molar mass to obtain a disperse solution and applied to steel blocks. After it was left to dry at room temperature for 24 hours, the curing process was carried out in a hot press machine at 120°C under six tons of pressure. When the bonded blocks reached thermal equilibrium, their mechanical properties were examined with a compression and tensile test device.

Adhesive Applications of p(GMA)

1g p(GMA) was dissolved in 10 mL of methyl ethyl ketone (MEK) in a 50 mL round-bottomed flask. 0.45 mol of 4,4′-diaminodiphenylmethane (DADFM) crosslinking agent was added to the solution corresponding to each mole of epoxy group and mixed until homogeneous using a magnetic stirrer. The obtained solution was applied to steel blocks of 2.5 × 6.5 × 1 cm dimensions with the help of a dropper to form a 0.2 mm thick film. After drying at room temperature for one day, the samples were subjected to curing at 110 °C and 6 MPa pressure

for one hour. After curing, the samples were kept at room temperature until they reached thermal equilibrium. The mechanical properties of the prepared samples were evaluated using compression and tensile testing devices.

Figure 7. Application of adhesive to metal surfaces.

Figure 8. Hot press equipment where the curing process is performed.

Figure 9. Curing of layers with hot press equipment.

The mechanical properties of the obtained single-effect adhesive joints were evaluated by tension-compression tests. The main purpose of the tensile test is to determine the elastic and plastic behavior of the materials under static load. In this direction, both the mechanical characteristics of the material and the optimization of the bonding parameters were aimed. Tensile tests of three different samples prepared using p(GMA) were performed on steel-steel plate pairs with a 5 kN capacity tension-compression device. According to the test results, the maximum strength was measured as 0.065 kN for steel plates. The damages occurring on the bonding surfaces after the tensile tests were examined by scanning electron microscope (SEM) and the images obtained revealed that the polymeric adhesive showed both cohesive and adhesive damage types under the applied mechanical stress.

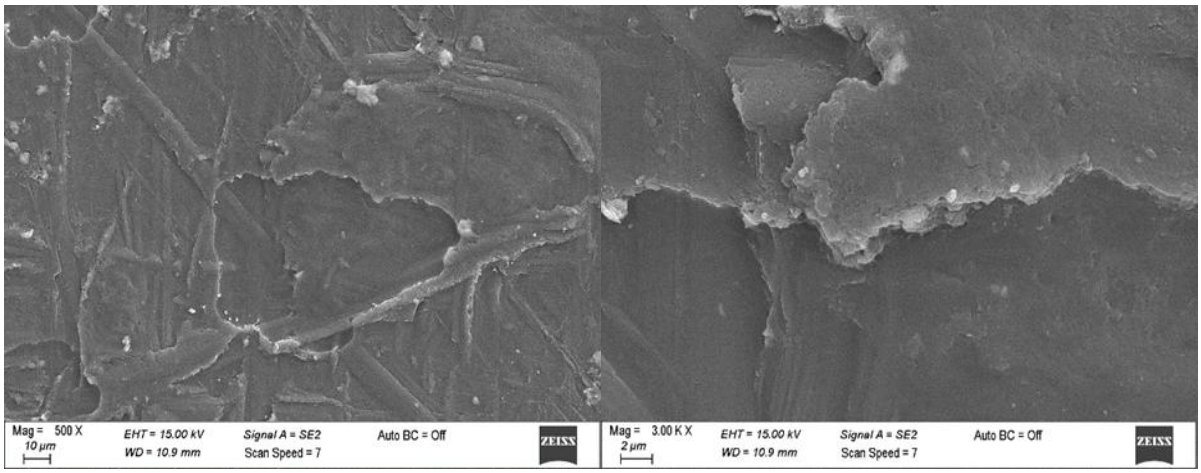

Figure 10. SEM images of p(GMA) cross-linked polymer.

MECHANICAL TESTS

Tensile-compression testing machines are versatile systems that can perform both tensile and compression tests, used to evaluate the mechanical properties of materials. The main purpose of these tests is to evaluate the mechanical properties of a material, such as durability and elasticity.

With the help of these devices, critical mechanical parameters such as tensile and compressive strength, elastic modulus (Young's modulus), elongation at break, yield stress, ductility of a material can be determined. At the same time, features such as creep or fatigue behavior such as deformation under long-term load can also be examined with these devices.
During the test process, the material sample is fixed between the upper and lower jaws of the device. A controlled tensile or compressive force is applied to the sample by means of a hydraulic or screw mechanism integrated into the device. The magnitude of the force is continuously measured by the load cell on the device, while the elongation or shortening of the sample is monitored by extensometers or digital sensors.

The obtained data is analyzed with the help of computer-controlled software and thus the stress-strain curve (σ-ε curve) is created, which shows the deformation behavior of the material. Mechanical properties such as the elastic limit of the material, plastic deformation capacity, and breaking point can be calculated from this curve.

Tensile testing is performed to examine the behavior of a material under tensile force. This test is widely used especially in ductile materials such as metals, plastics, composites and

elastomers. Tensile tests help to understand how much the material can be stretched and what properties it exhibits up to the point of rupture.

Compression tests are generally applied to brittle materials (e.g. ceramics, concrete). In these tests, the sample is compressed and the crushing resistance and deformation behavior of the material under pressure are evaluated.

Thanks to the data obtained from these test devices, it is possible to compare different types of materials, select the appropriate material in engineering designs and develop new materials. Tensile-compression test devices are widely used in many fields, especially in materials science, civil engineering, polymer technology, composite material development, automotive and aviation industries.

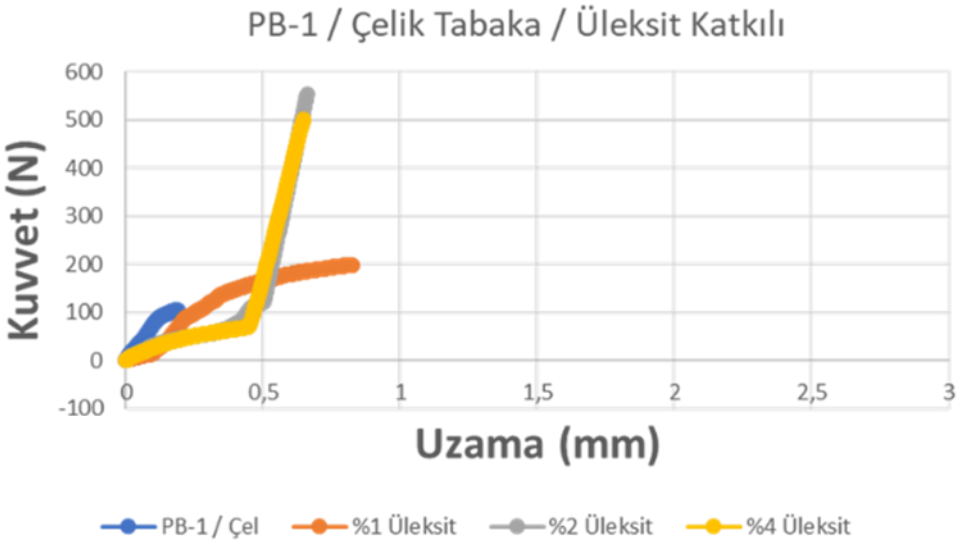

Figure 11. Elongation at break graph of PB-1 (% 1,2,4 Ulexite) composite polymers on steel blocks.

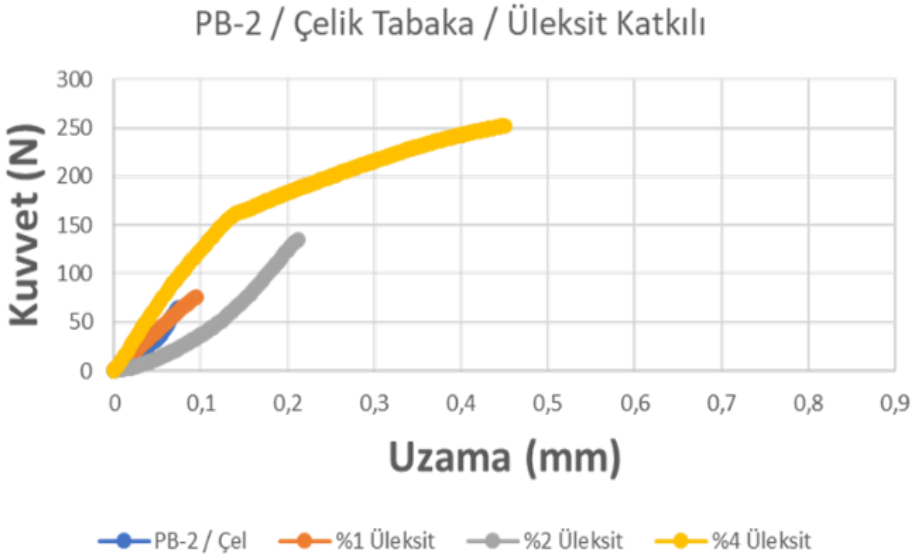

Figure 12. Elongation at break graph of PB-2 (% 1,2,4 Ulexite) composite polymers on steel blocks.

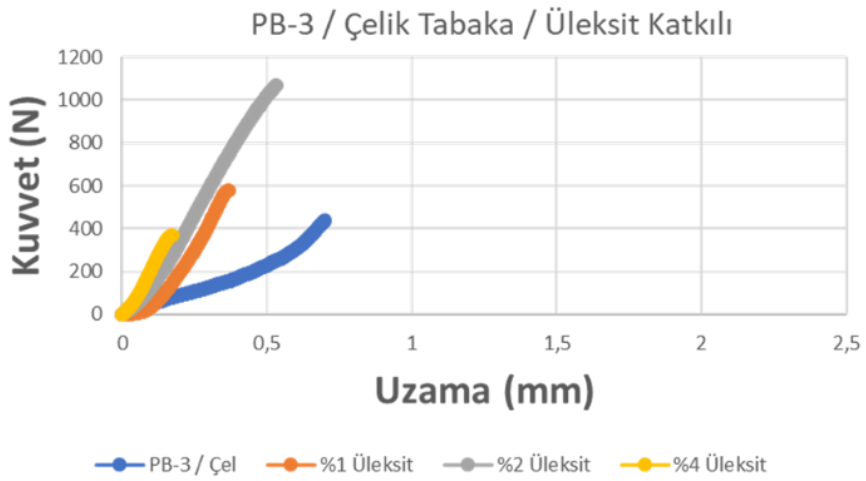

Figure 13. Elongation at break graph of PB-3 (% 1,2,4 Ulexite) composite polymers on steel blocks.

In the graphs, 1%, 2% and 4% ulexite additives were added to the adhesive formulations numbered PB-1, PB-2 and PB-3 and applied to steel surfaces. The obtained force-elongation curves clearly show the effect of the additive ratio on the mechanical performance of the adhesive. As seen in the graphs, 4% ulexite additive on steel surfaces reached the highest force values in all samples and significantly increased the bonding strength. Samples with 2% additive exhibited high force at shorter extensions and showed a more brittle structure. 1% additive provided a limited improvement. In general, as the ulexite additive increased, the mechanical performance of the adhesive also increased.

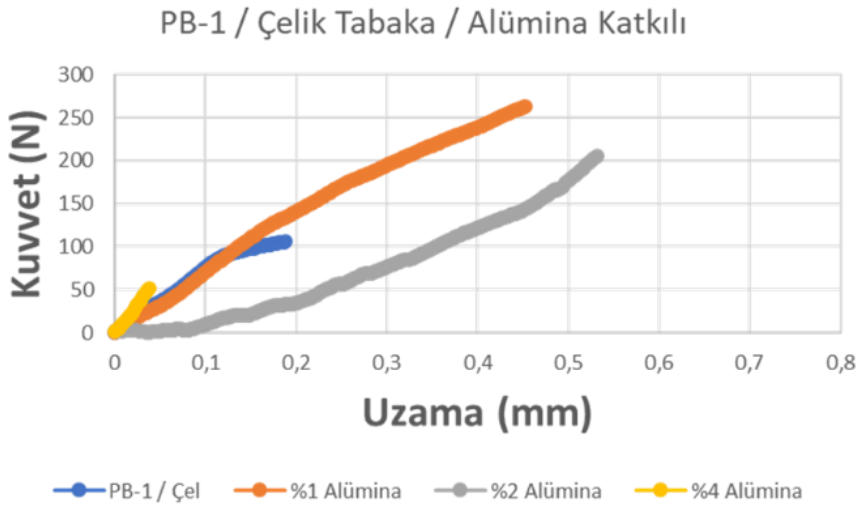

Figure 14. Elongation at break graph of PB-1 (% 1,2,4 Alumina) composite polymers on steel blocks.

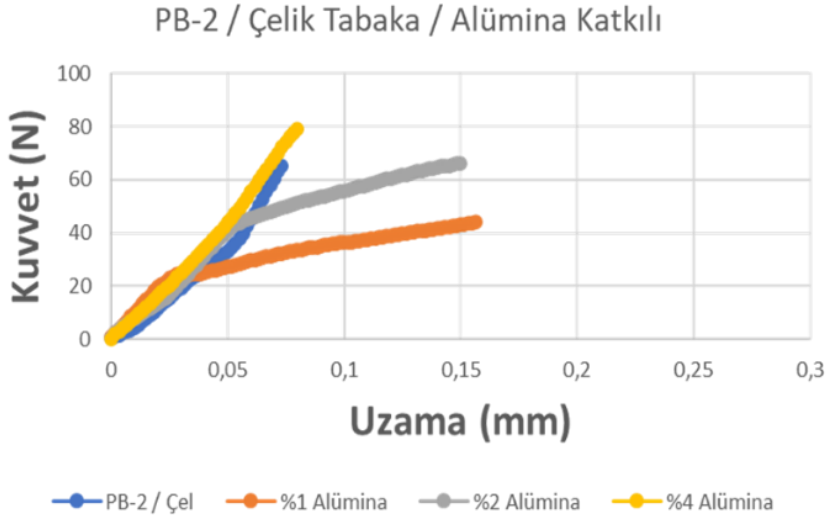

Figure 15. Elongation at break graph of PB-2 (% 1,2,4 Alumina) composite polymers on steel blocks.

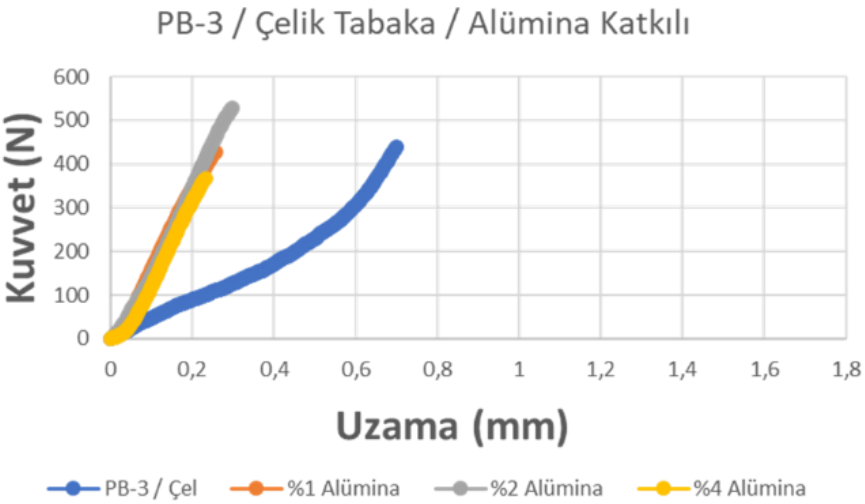

Figure 16. Elongation at break graph of PB-3 (% 1,2,4 Alumina) composite polymers on steel blocks.

In the study conducted by adding 1%, 2% and 4% Alumina additives to the adhesive systems, it was observed that the mechanical performance increased especially at 1% and 2% compared to the additive-free system. While the PB-1 and PB-3 samples showed the best performances with 2% and 1% additives, respectively, the 4% additive was effective only at short extension distances. These results show that Alumina additive can increase the tensile strength of adhesives; however, the performance does not always increase when the additive rate is high.

YOUNG MODULUS

The elastic modulus is the resistance of a material to deformation in the elastic range. As the modulus value increases, the stiffness of the material increases, allowing it to carry higher stresses even at the same rate of elongation. Therefore, high modulus materials are harder, less flexible, and generally more brittle.

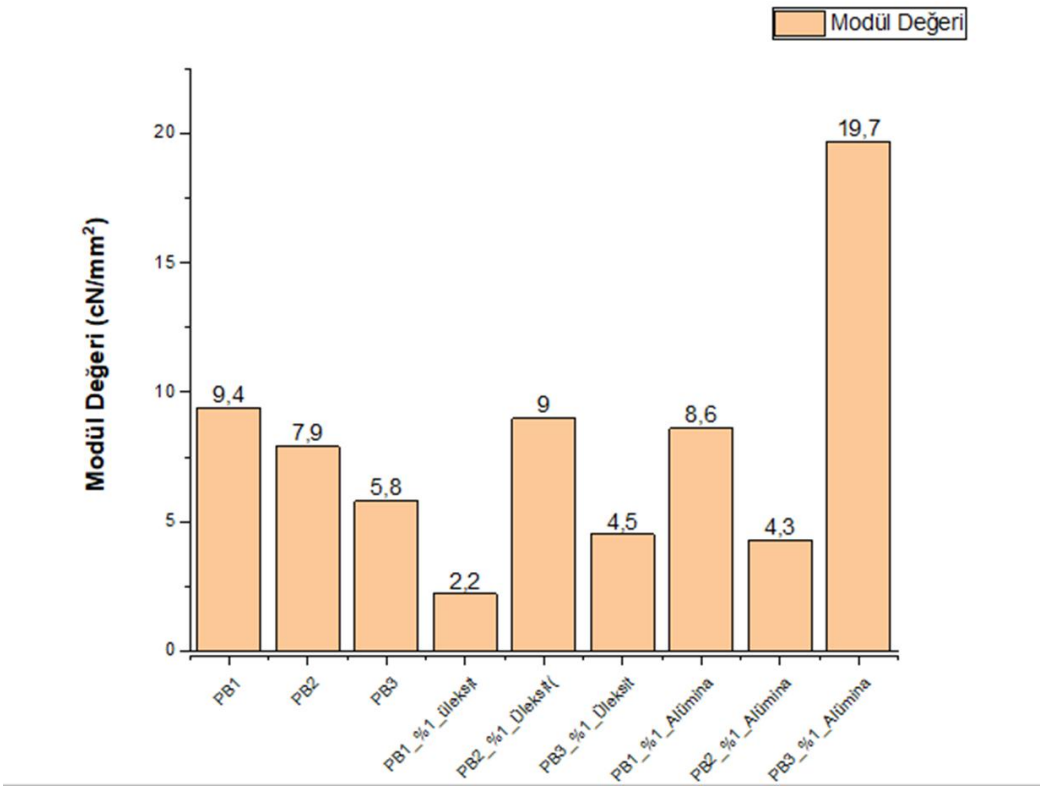

Figure 17. Young modulus values of PB-1, PB-2 and PB-3 polymers and composites on steel-steel plates.

VERITY

When we look at the undoped copolymers (PB-1, PB-2, and PB-3), it was observed that the elastic modulus of PB-1 was higher. In this case, PB-1 is more rigid and hard than the other copolymers. Its mechanical performance is better.

It shows that the effect of ulexite addition on the modulus varies depending on the polymer matrix and is not compatible with every polymer. While it showed a synergistic effect with PB-2, it caused a decrease in mechanical properties with PB-1 and PB-3.

It is shown that the alumina additive is in very good harmony with the PB-3 copolymer and creates a strong effect. It was observed that the additive did not provide the desired level of improvement in the other two copolymers.

In conclusion, alumina is an effective additive that can significantly increase the elastic modulus of the adhesive when used in appropriate proportions, while ulexite additive showed limited effect on the mechanical performance.

CONCLUSION

It is a result of the linear relationship between the unit strain in the elastic deformation region and the normal stress (tensile or compressive stress) and is defined as the stress per unit strain. Original, new generation polymer and copolymer materials have been synthesized for use in adhesive applications. It has been observed that these materials synthesized as adhesives increase adhesion properties and interfacial interactions with surfaces.

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AN EFFICIENT STORAGE OPTIMIZATION TECHNIQUES FOR LARGE DATABASE

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ABSTRACT

In recent days,organization's data is the main asset for any organization. Because of daily operational activities, data will grow up. Data in great quantity will be a problem in the organization if they cannot use it relevantly.The applications used for very large dataset are different from traditional data warehouse as it contains non-transactional information. A large amount of data is accumulated, which is needed to be accessed in least amount of time when complex queries are executed in present applications of data warehouses.For very largedatabase, the organization has to take extra effort to choose the important to process. If data is not be used in correct manner, it is only be trashed in that organization. In order to avoid the problem, we may use datamining techniques. These are used to discover gems of patterns in the vast quantity of data that has been captured in the normal course of running the enterprises. When the data needed for getting potential of students in any academic institutions is compared with the other academic institutions data, searching takes the lot of times for checking the similarities, relationship between both the data. Hence there is a standard and generalized pattern needed to access these data in lesser time. In this paper we have proposed to design a generalized pattern for getting optimum utilization of input/output devices on very large dataset particularly for getting potential of students in any academic institutions. Different parameters are used to compare the performance. The main aim of this paper is to motivate the need to reduce disk I/O. For this purpose, we have developed a choice based application called ThaMalalgorithm to cluster the potential of students on their choice. The expected outcomes of this paper will be the effective utilization of I/O devices that are bought in a transaction together. For the effective utilization of i/o resources, we can arrange their choices which are frequently transacted in a same time.

1. Introduction

For a small database or medium database, we may process the entire database as a single partition[1]. As the database size grows, i.e from large to very large database or big data, the size of the TID-lists also grows and we may no longer be able to fit in main memory the TID-lists that are being joined [2]. This leads to thrashing and degradation of the performance of the entire system. We must choose the partition size such that at least those itemsets that are used for generating the new large itemsets can fit in main memory. We assume the number of such itemsets is at most a few thousand. We use heuristic approach to estimate the partition size on the basis of available main memory and the average length of transactions [2,3]. Sampling can also be used to estimate the number of large itemsets and their average *support* which can be used to compute the partition size.

The main operations on very large dataset include searching of the required items and matching of certain patterns. This is very complex and tedious task to handle, because finding a particular pattern for identification of potential students can even take days, so pattern matching or searching becomes difficult in the systems as it takes considerable amount of time and memory consumption depending upon the queries which are complex and iterative. The ability to answer these complex queries efficiently depends upon a major factor 'optimum utilization of all input/output resources.If the main memory used for the transaction is complex, the data loads quickly but the query response is slows [1,3,4]. If there are medium amount of main memory, the data loads quickly and there will be more storage requirements but the query response is good. This is true with very large data sets and complex queries.

Considerable amount of time is taken by the query to be processed is more due to large size of memory usage. The space and time play an important role in choosing the optimization of data in data warehouse. Usually if the space used by any transaction is large then the results are achieved in short time and on the other side, if the space used by any transaction is small then the results are achieved in greater amount of time. So there is a tradeoff between the time consumed and the space used for a particular transaction [3,5]. Important factors which are need to be improved are Response time, Searching time/Scan time, and Memory Usage.

2. Our Algorithm

Algorithm

{
L1 = {large l-itemsets};
for (k = 2; Lk-l ≠ 0; k++) do
{ck = thabu-gen(Lk-1);
for all transactions t Є D, do
{ Ct = subset, (Ck, t);
For all candidates c Є Ct, do
c.count++;
}
Lk; = {c Є Ck | c.count ≥ MinSup}
}
Answer = UkLk;
}

Procedure 1: our new algorithm

The above *algorithm* takes the advantage of structure within the rules themselves to reduce the search problem to a more manageable size.As our algorithm use candidate itemset generation technique, the improvement is mainly due to better technique for generating the *counts*. In our algorithm *counts* are generated by the subset operation where *itemsets* from a

candidate set are compared with all transactions during each pass for inclusion to determine their *counts*. The cost of subset operation per itemset increases in later passes as the length of the itemsets increase. Assume the number of candidate itemsets is 1,000 and that there are 1 million transactions in the database. This requires 0.01 x 1,000 x 1 million x 4, or 40 million basic integer compare operations.

The partitioned approach in our algorithm allows using more efficient data structures for computing the counts for the itemsets. The cost of generating the s*upport* decreased during later passes as the lengths of the TIDlists become smaller. For the purpose of illustration, assume that the number of partition is 1.

Our algorithm is to motivate the need to reduce disk I/O. Our algorithm reads the database multiple number of times. The exact number depends on the minimum support and the data characteristics and cannot be determined in advance.

The number of partitions varied from 1 for 100K transactions to 100 for 10M transactions for this algorithm. The execution times are first normalized with respect to the size of the database and then with respect execution times taken by the Partition algorithm for 1,00,000 transactions. The initial jump in the execution time (from about 1.3 to 1.9) is due to the increase in the number of partitions from 1 to 4. As expected, this increases the size of the global candidate set and hence an increase in the execution time. However, as the number of partitions is increased, size of the global candidate set does not increase correspondingly as more and more local large itemsets are common. The execution time was relatively linear from 4,00,000 transactions to 10 million Transactions.

3. Experiments

In this section, we describe the performance results of our algorithm. The experiments were run on Pentium @3.0 GHZ, 1TB of main memory with 800 GB HDD. All the experiments were run on synthetic data. Initiallythe experiments showed that the performance of our algorithm is superior.

a) Synthetic Data

It is used to simulate an admission pattern for any academic institutions and obtain a student admission pattern for service oriented applications [3,5,6]. The length of a transaction is determined by Poisson distribution with mean p = |T|. The transaction is repeatedly assigned items from a set of potentially maximal large itemsets, T until the length of the transaction does not exceed the generated length. The length of an itemset in T is determined according to Poisson distribution with mean p equal to |I|.

The transactions in a transaction-set are chosen such that a fraction of the transactions are common to the previous transaction determined by an exponentially distributed random variable with mean equal to a correlation level. The remaining transactions are randomly picked. Each transactions in T has an exponentially distributed weight that determines the probability that this transaction will be picked. Not all transactions from the transaction-set picked are assigned to the transaction. Transactions from the transaction-set are dropped as long as a uniformly generated random number between 0 and 1 is less than a corruption level, c. The corruption level for transaction-set is determined by a normal distribution with mean 0.5 and variance 0.1.

Six different data sets were used for computing performance. Table1 shows the parameter settings for each data set. For all data sets N was set to 1,000 and |L| was set to 2,000. Table 2 and Figure-1 showed the execution times of our own developed algorithm for the above six synthetic datasets for decreasing values of minimum support. Since the datasets contained about 1,00,000 transactions with the largest dataset, only about 8.4 MB, we could run our

algorithm setting the number of partitions to 1. However for comparison, we also ran the experiments setting the number of partitions to 10. These results are indicated as Partition-l and Partition-10 in the figure.

Since we have not implemented complete buffer and disk management, we did not include disk I/O times in the execution times to keep the comparison uniform. The execution times increase for our algorithm as the minimum support is reduced because the total number of large andcandidate itemsets increase. Also, as the average length of transactions increase, the number of large and candidate itemsets also increase.

Table 1: Parameter Settings

S.No	**Name**	Avg size of Transactions **|T|**	Average size of maximal potentially large itemsets **|I|**	Number of Transactions **|D|**	**Size in MB**
1	T5.I2.100K	5	2	100K	2.4
2	T10.I2.100K	10	2	100K	4.4
3	T10.I4.100K	10	4	100K	
4	T20.I2.100K	20	2	100K	8.4
5	T20.I4.100K	20	4	100K	
6	T20.I6.100K	20	6	100K	

For these datasets, Partition-l performed better than partition-10 in all cases as expected. The reason is that the Partition-10 tests support for more itemsets which have only local support. Except for cases where the minimum support is high, Partition-l performed better than our algorithm. Even Partition-10 performed better in our algorithm in most cases for low minimum support settings. The reason why our algorithm performs better for higher minimum support settings is that partition has the overhead of setting up the TID-List data structures. However, at these minimum supports [5,7] the large and candidate itemsets are very few and in some cases none at all. So, Partition does not benefit from setting up the data structures. Partition-10 its performance is worse than our algorithm for the dataset T20.12.100K at minimum support of 0.25%. The reason was that a large number of itemsets were found to be locally large which later turned out to be small. However, this behavior did not repeat for any other case. We attribute it to the characteristics of that particular dataset.

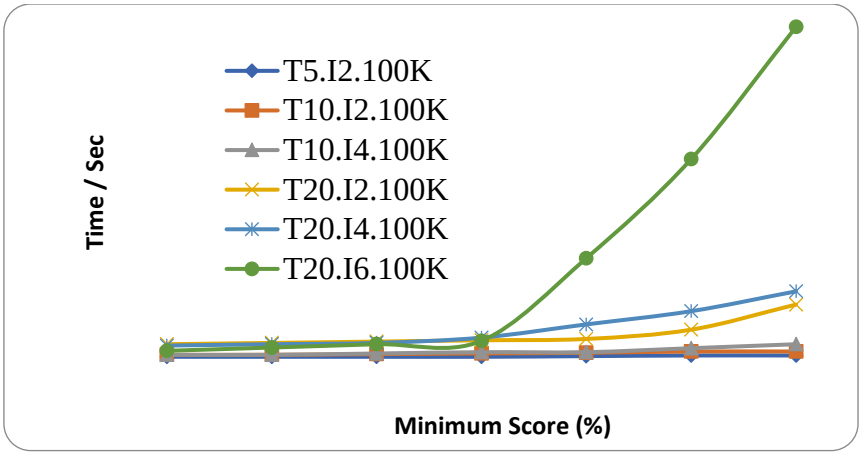

Figure 1: Execution time for our algorithm by using 6 different TIDs

At the lowest minimum support setting, the least improvement was 10% (10 seconds for our algorithm for Tl0.12.100K). The best improvement was about 81% (707 seconds for our algorithm for T20.16.100K). This is an improvement by a factor of 5. It should be noted that the improvement in the execution times for our algorithm shown in Figure1 is mainly due to the reduction in the CPU overhead and not due to the reduction in I/O [4,8]. The reason is that the database is only 8.4 Mbytes which is too small to significantly affect the total execution time.

Table 2 Number of comparison operations

Algorithm	**Minimum Support**	
	0.75%	0.25%
Our algorithm	4,12,904	1,04,95,190
AprioriTID	58,452	19,78,077

Then, in our algorithm the operation of counting supports involves performing just 1,000 intersection operations. Assume that each transaction contains on an average 10 items and that there are 1,000 distinct items. Then on an average the length of a TID-list is 1 million x 10 / 1,000, or about 10,000. So the overall cost is about 1,000 x 10,000, or about 10 million basic integer compare operations. However, if the number of partitions is more than 1, this value can be much larger. We have compared the actual number of comparisons performed by various support levels of our algorithm. It should be noted that the actual execution times also include generation of data structures, generation of candidate itemsets, and in the case of our algorithm and hence do not reflect the figures shown in the table which compares only the cost of generating supports.

b) Improvement in Disk I/O

We measured the number of read requests for data for various support levels of our algorithm for the datasets in Table1. The page size was set to 4KB. The results are shown in Figure 2. The best improvement we found was about 87% for T20.16.100K at minimum support of 25%. This is an improvement by a factor of 8. The least improvement for this minimum support was 60% represents that the minimum support is set very high, no large itemsets are generated. In this case, the various support levels of our algorithm read the database only once in the factor of 2.5.

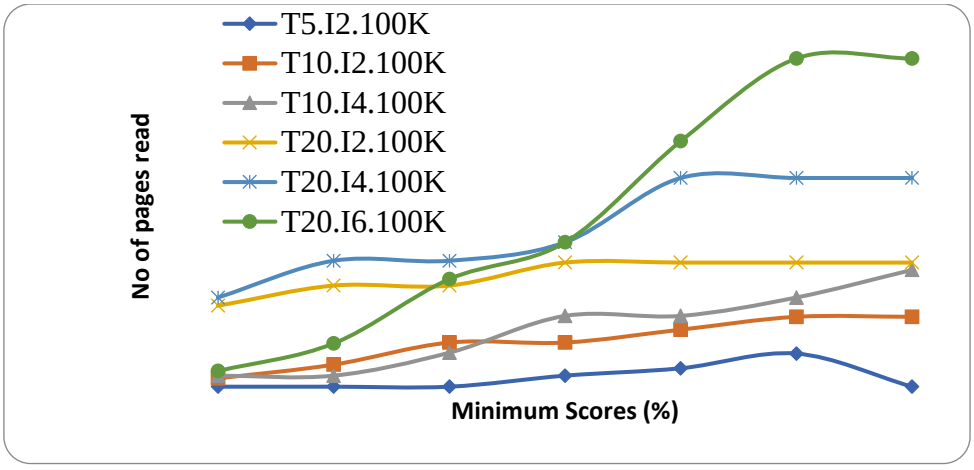

Figure 2: Number of database read request

c) Scale-up Experiments

We have studied the scale-up characteristics of the ThaMalalgorithm by varying the number of transactions from l,00,000, to 10 million. All other parameter settings were same as T10.14.100K. The results are shown in Figure 3.

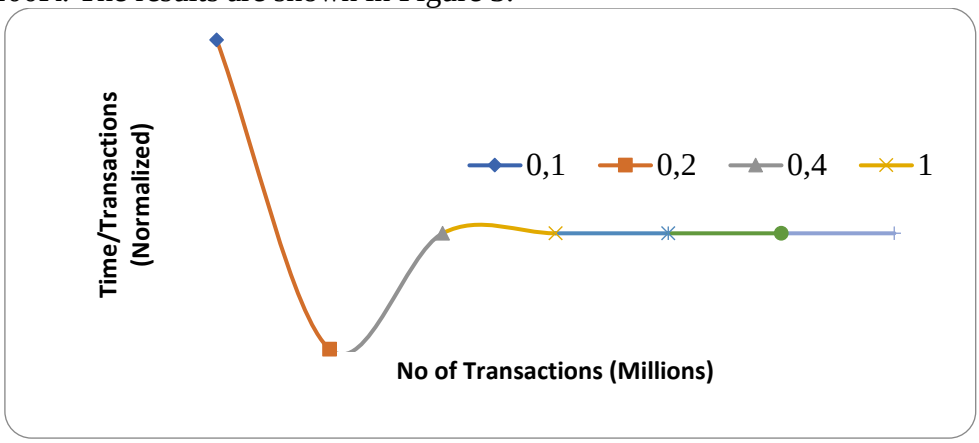

Figure 3: Number of Transactions scale-up

We also studied the performance of our algorithm for average transaction size and the average size of maximal potentially large itemset scale-up. For this experiment, we varied the transaction length from 5 to 50. The size of 111 was varied from 2 to 6. The physical size of the database was kept roughly constant by keeping the product of the number of transaction and the average transaction size constant. The number of transactions varied from 2,00,000 for the database with an average transaction length of 5 to 20,000 for the database with the average transaction length of 50.

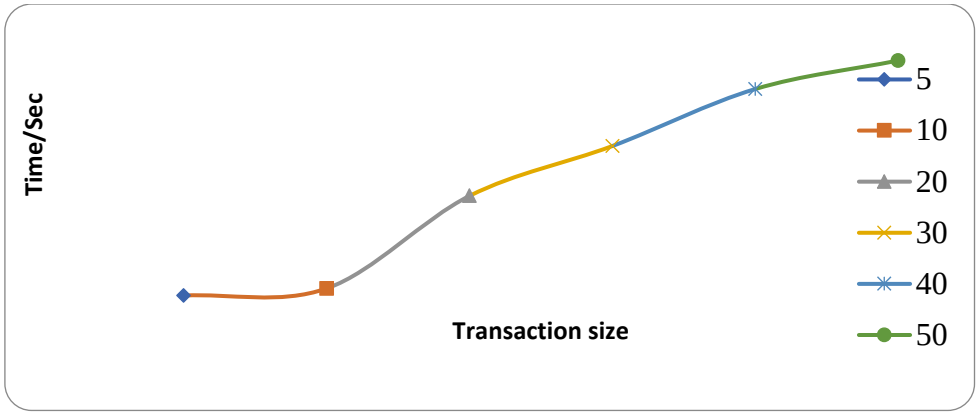

Figure 4: Transaction size scale-up

The minimum support level [8,9] was fixed in terms of the number of transactions. We ran the experiments for minimum support levels of 750 and 250. The results are shown in Figure 4. This algorithm exhibits marginally inferior scale-up compared to any other algorithm when the minimum support is high (750) as it spends more and more time initializing the data structures without deriving much benefit in processing cost. However for lower minimum support i.e., high processing cost, the scale-up is superior to our algorithm, because the processing cost increases slower than that of our algorithm.

Conclusion

The Very large dataset or big data warehouse plays a crucial role in order to perform important operations like pattern identification, matching but challenge is large size of transactional data warehouse, which encapsulate string of large length. Different techniques has been used and analyzed using different types of queries on different size of datasets in identification of potential students data warehouse in order to perform operation in efficient manner.

We have described an algorithmic approach for discovering an optimum level of disk i/ousage to improve the number of admission procedures for any academic institutions its volumes are high in various ways. It is exclusively useful for very large databases particularly big data. An important contribution of our own approach is that it drastically reduces the I/O overhead. This feature may prove useful for many real-life database mining scenarios where the data is most often a centralized resource shared by many user groups and may even have to support on-line transactions. Interestingly this improvement in disk I/O is not achieved at the cost of CPU overhead. In addition, the algorithm has an excellent scale-up property. The problem in the algorithm which is used to get the potential students for any academic institutions is of accurately estimating the number of partitions given the available memory. In future, we have proposed to extend this work by parallelizing the algorithm for a shared multiprocessor machine.

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YAPI DÖŞEME VE DUVARLARINDA FARKLI TİPTE SES YALITIM UYGULAMASININ SES AZALTIMINA ETKİSİNİN İNCELENMESİ

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ÖZET
Dikey mimari uygulamasının getirdiği en önemli problemlerden bir tanesi olarak yapı kabuğu içerisinde oluşan gürültü kirliliği söylenebilir. Bitişik mahaller ve döşeme elemanlarından doğrudan etkilenen bu problemlerin insan sağlığı üzerine etkisi yadsınamayacak seviyede önemlidir. Son zamanlarda bu durum yayınlanan yönetmelikler aracılığıyla yasal denetime tabi tutulsa da malzeme kalitesi, çeşitliliği ve uygulaması problemlerin çözümüne yardımcı olamayabilmektedir. Bu amaçla bu çalışmada, duvar ve döşeme elemanların tasarımında farklı özeliklere sahip malzemeler kullanılarak, yönetmeliğe uygun hesaplama yapan paket program yardımıyla ses azaltım değerleri belirlenmiştir. Özellikle uygulama esnasında oluşabilecek farklılıkların nihai sonuçlarının değerlendirilme fırsatı noktasında proaktif bir bakış açısı yaratacağı söylenebilir.
Anahtar kelimeler: Duvar, döşeme, ses yalıtımı

AN INVESTIGATION OF THE EFFECT OF DIFFERENT TYPES OF SOUND INSULATION APPLICATION ON SOUND REDUCTION IN BUILDING FLOORS AND WALLS

ABSTRACT

Noise pollution within the building envelope can be said to be one of the most important problems caused by the application of vertical architecture. The impact of these problems, which are directly affected by adjacent spaces and floor elements, on human health is undeniably important. Although this situation has been subject to legal control through recently published regulations, material quality, diversity and application may not help solve the problems. For this purpose, in this study, sound absorption capacity values were determined by using materials with different properties in the design of wall and floor elements, with the help of a package program that makes calculations in accordance with the regulation. It can be said that it will create a proactive perspective, especially in terms of the opportunity to evaluate the final results of the differences that may occur during the application.

Key words: Wall, floor, sound isolation

1. GİRİŞ

Binalarda ses yalıtım performansı, binanın bütünü ya da bağımsız olan bir bölümü için kabullenilen ses seviyelerinin gürültü gösterimi tipinden, yasal mevzuata uygun olup olmadığının hesap ve ölçüm metotlarıyla belirlenmesini ifade etmektedir [1].

Gürültü kabul görmüş bir çevre kirliliği olmakla birlikte insan sağlığı üzerinde yıpratıcı bir etkisi olan ve özellikle kapalı alanlarda oluştuğunda konforsuzluk ve rahatsızlık hissi yaratan bir etkendir. Gürültüyü ortadan tamamen kaldırmak ya da oluşmasını engelleyebilmek imkânsız olmasına rağmen, etki bileşenlerini ve düzeylerini bilerek bunların asgari düzeyde kalmasını sağlayabilmek için teknik imkanlar ve yöntemler bulunmaktadır [2].

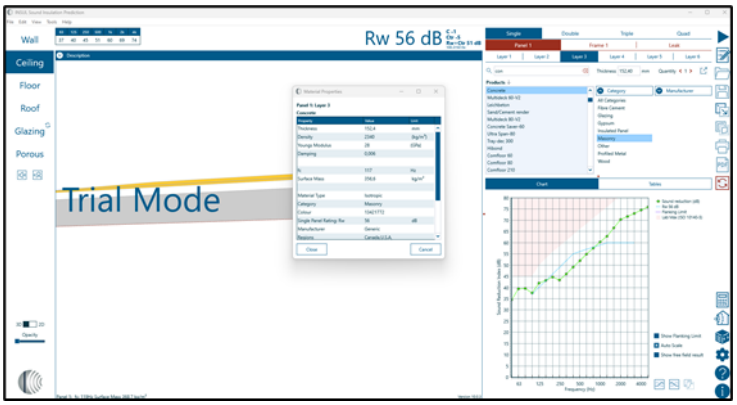
Gürültünün sınır değerlerde tutulmadığı durumlarda insan sağlığı için önemli sorunlar oluşabilmektedir. Bunlar, işitmede kayıp yaşanması, solunum üzerinde olumsuz etki, tansiyon değişimi, cilt rahatsızlıkları, öfke patlamaları, uyku düzensizlikleri, gerginliğin artması, öğrenme güçlüğü, motivasyon ve verimlilik kaybı şeklinde sıralanabilir [3].

Dünya Sağlık Örgütü insan yaşamının normal seyrinde devam edebilmesi açısından kabul edilebilir gürültü seviyesi değerini ortalama 55 dB olarak belirtmektedir. Ekonomik İşbirliği ve Kalkınma Örgütü ise bu değerin 55-60 dB aralığında olduğunu söylemektedir. Bu sınır değerler eşik şiddet değeri olarak kabul edildiğinde özellikle yapı kabuğu üretiminde kullanılacak olan yapı malzemelerinin seçiminde akustik performans özelliği gösterebilmesi çok önemlidir [4,5].

İşitsel konforun tesis edilmesinde en önemli unsur yapı kabuğunun Dünya Sağlık Örgütü'nün de belirtmiş olduğu sınır değeri karşılayabilecek nitelikte olmasıdır [6]. Özellikle dış ortam kaynaklı gürültülerde göz önüne alındığında yapı elemanı tasarımında detay ve malzeme özeliklerinin iyi tanınması ve belirlenmesi gerekmektedir. Bu amaçla bu çalışmada, döşeme ve duvar elemanlar için farklı uygulama detayları ve farklı malzeme seçenekleri ile uygulayıcı ve kullanıcılara öneriler sunulmaktadır.

2. MATERYAL ve METOT

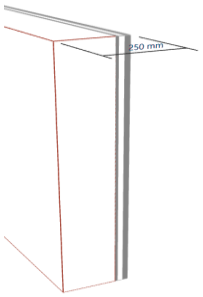
Bu çalışmada farklı duvar ve döşeme kesitlerinde kullanılan malzemelerin ses azaltımı üzerine olan etkisi INSUL paket programının demo versiyonu yardımıyla araştırılmıştır (Şekil 1). Yapı grubu klasik konut yapıları için sınırlandırılmıştır. Duvar ve döşemelerde farklı kesit ve malzemeler üzerindeki ses kayıpları için farklı senaryolar simüle edilerek ses azaltımı değerleri elde edilmiştir.



Şekil 1. INSUL demo versiyonu

Duvar ve döşeme kesitleri belirlenirken uygulamada oldukça sık karşılaşılan tuğla, gazbeton ve taş yünü malzemeler tercih edilmiştir. Duvarlarda ses yalıtım malzemesi uygulama kalınlığı 40mm olarak belirlenmiştir. Döşeme kesitlerinde farklı birim ağırlık değerlerine sahip döşeme betonları üzerine 40mm yalıtım malzemesi ve üzerine döşeme kaplaması uygulaması tercih edilmiştir. Duvar ve döşeme kesitlerine ilişkin kesit detayları Tablo 1'de verilmiştir.

Tablo 1. Duvar ve döşeme kesitleri

	Tuğla Duvar	**Gazbeton Duvar**
Duvar Elamanlar		
	Asmolen Beton Döşeme	**Beton Döşeme**
Döşeme Elamanlar		

3. BULGULAR ve TARTIŞMA

Farklı tipte duvar elemanı ve döşeme tipi uygulamaları sonrasında oluşan analiz verilerine ilişkin bulgular Tablo 2.'de verilmiştir.

Tablo 2. Duvar elaman bulguları

Duvar Elamanı	Boyut	Rw (dB)
Tuğla Duvar	13,5'luk	47
	8,5'luk	42
Gazbeton Duvar	20'lik	45
	10'luk	39

Tablo 3. Döşeme elaman bulguları

Döşeme Elamanı	Yalıtım malzemesi	Rw (dB)
Asmolen beton döşeme	Taş yünü	49
	Kauçuk	49
Beton Döşeme	Taş yünü	56
	Kauçuk	56

Duvar elamanı bulguları incelendiğinde en yüksek ses azaltım değerleri 13,5'luk tuğla ile imal edilen duvarda 47 dB olarak elde edilmiştir. 20'lik gazbeton malzeme ile imal edilen duvarda ise ses azaltım değeri 45 dB olarak gözlenmiştir. Kullanılan duvar malzemesi geometrisindeki küçülme ses azaltımı değerlerinde de düşüşe sebep olmuştur. Bu durumda da tuğla malzemenin ses azaltım performansının gazbeton malzemeden daha iyi olduğu tespit edilmiştir. Tuğla içerisinde bulunan boşluk kanallarının gazbeton morfolojisinde yer alan boşluklardan çok farklı olması ve dolayısıyla ses azaltım indeks değerlerinde bu değişikliğe sebep olduğu söylenebilir. Bulunan sonuçlar Aksoylu vd.'nin [7] çalışması ile benzerlik göstermektedir.

Döşeme uygulamalarında asmolen döşemelerin ses azaltım değerlerinin normal beton döşemelere göre daha düşük değerlerde olduğu tespit edilmiştir. Beton döşeme ile gerçekleştirilen ses azaltım değerleri 56 dB değerinde iken asmolen uygulamalarda bu değer 49 dB olarak elde edilmiştir.

4. SONUÇ ve ÖNERİLER

Farklı tipte taşıyıcı ve duvar elemanlar kullanılarak oluşturulan uygulama simülasyonları sonrasında elde edilen sonuçlara göre;

- Tuğla duvar ve gazbeton duvar uygulamalarında farklı ses azaltım değerleri elde edilmiştir. Duvar malzemesi geometrisindeki değişiklikle birlikte ses azaltımı değerlerinde daha iyi sonuçlar elde edilmiştir.
- Duvar elemanı malzemesinde en iyi ses azaltımı değerleri 13,5'luk tuğla ve 20'lik gazbeton malzemelerde tespit edilmiştir.
- Döşeme uygulamalarında döşeme tipi değişikliği ses azaltımı değerlerinde belirgin şekilde değişiklik göstermiştir.
- Döşeme uygulamalarında en iyi sonuçlar beton döşemelerde elde edilmiştir. Asmolen döşeme uygulamasının ses azaltımı performansının düşük kaldığı gözlenmiştir.
- Döşeme uygulamalarında taş yünü ve kauçuk kullanımı arasında bir fark tespit edilmemiştir.

Yapı zati yükünün azaltılması noktasında asmolen döşeme uygulamasının avantajları bilinmektedir. Ancak hem yapının deprem davranışı noktasında oluşturduğu dezavantajlar hem de akustik konfor amacıyla yapılan bu çalışmada elde edilen ses azaltımı değerleri asmolen döşeme uygulamasının kullanımı hakkındaki dezavantajları göstermektedir. Özellikle farklı malzemeler ile birlikte farklı uygulama tiplerine ilişkin çözümlemelerin yapıldığı ve verilerinin aktarıldığı çalışmaların yapısal konfor uygulamaları açısından önemli ve faydalı olacağı önerilmektedir.

TEŞEKKÜR

Yazar, bu çalışmaya INSUL paket programının lisanslı demo versiyonu ile katkıda bulunan Subera Arge Danışmanlık şirketi ve çalışanlarına teşekkür eder.

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NANOTECHNOLOGY AND DAIRY INDUSTRY: PROSPECTS AND CHALLENGES

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ABSTRACT
Nanotechnology has revolutionized the food industry in terms of processing, packaging, storage and development of innovative products due to its unique advantages such as; controlled release of functional ingredients, antimicrobial properties, increased shelf life, improvement of taste, flavor, texture, stability, and increased mechanical and thermal resistance. The dairy industry also benefits from this progress. The most common use of nanotechnology in the dairy industry is the development of antimicrobial films prepared with nanoparticles of antimicrobial compounds, essential oils, proteins and polysaccharides for cheese preservation, incorporation of antimicrobial and antioxidant compounds, especially natural spice and plant extracts within the cheesemaking process through nanoemulsion and nanoencapsulation methods, nanocomposite coatings for the inhibition of pathogens and spoilage bacteria on the surface and within cheeses. Nanotechnology offers the enhancement of textural and rheological properties of dairy desserts and ice cream by improving the stability, thereby influencing the sensory acceptance of the products. Also, fast pathogen and spoilage bacteria detection by nanosensors in milk and dairy products is of great importance. However, nanotechnology is a field that increases concerns about food, based on health-related issues and ethical arguments. Existing regulations are not sufficient yet to assess the risks posed by nanofoods and nanoparticle containing packaging materials. Therefore, the success of the nanotechnology applications in dairy industry will depend on consumer acceptance and deep regulatory research.
Key Words: Nanotechnology, dairy, nanoparticle, nanoemulsion, nanoencapsulation, nanosensor

INTRODUCTION

In recent years nanotechnological applications have become so involved in our lives, especially considering our diet. Nanotechnology has revolutionized the food industry due to its unique advantages such as; controlled release of functional ingredients during digestion, enhanced antimicrobial properties, increased shelf life, improved taste, flavor, texture, stability, and increased mechanical and thermal resistance. The dairy industry also benefits from this progress.

Determining the milk quality

Nanotechnology is involved in quality monitoring of milk by nanosensors. They are excellent tools for ensuring quality and have advantages of cost-effectiveness and simple synthesis. Nowadays nanosensors are used in early detection of pathogens, allergens, toxins and heavy metals, thereby targeting quality control of milk and dairy products. They are used as labels and reporters that are fast, selective and sensitive compared to conventional methods. A nanosensor is composed of a receptor that interacts with the target analyte, and a transducer converting the response into electrical, electrochemical or optical signals. Carbon nanotubes, quantum dots, gold, iron oxide and nanofibers are usually used for the manufacture of nanosensors.

Nanosensors are successfully used for rapid detection of food borne pathogens. Li et al. (2024) synthesized nanosilicons utilized as receptors to develop a nanosensor. By coupling with machine learning algorithms, the nanosensor reaches high performance in identifying eight pathogens at low levels in milk. A fluorescent switching sensor was designed for the detection of *Staphylococcus aureus* (*S. aureus*) in milk, where graphene oxide nanoparticles (NPs) were used as a fluorescence quencher (Zhang et al., 2023). A reliable and selective sensor was obtained with a detection limit of 1 cfu/mL. There are also commercial nanosensors for the detection of allergens and pesticides in dairy products and also used for milk authentication. For example, Tellspec Incorporated® markets nanosensors for rapid, nondestructive quality control and authenticity of dairy samples, and successfully used for the rapid detection of allergens. Carbon nanotubes decorated with molybdenum selenide nanoflowers and gold NPs were used for the detection of kanamycin, a pesticide in milk, although in low concentrations (Azadbakht & Abbasi, 2019). An aptamer-DNAzyme conjugated biosensor was developed for detection of melamine in raw milk samples, displaying significantly higher signal intensity at 2 mM of melamine (Kaneko et al., 2018). Silver nanocubes synthesized by Hegde et al. (2021) were successful at the detection of formaldehyde in milk. Also, an immunosensor was developed by An and colleagues (2020) with a nanocomposite of graphene oxide-chitosan and cerium oxide-chitosan, which lead to rapid detection of aflatoxin M1 in milk with high accuracy. A carbon nanotube electrode for the voltammetric determination of lead and cadmium ions in milk was developed successfully (Gayathri et al., 2023).

Improvement of dairy processing

In dairy processing, nanotechnology helps for texture improvement, achieving homogeneous products, and the improvement of aroma, flavor and bioavailability. In a study, β-carotene NPs were used in ice cream, resulting with a uniform dispersion of small ice crystals, preventing their enlargement and the creamy consistency effects the overall texture (Hari et al., 2023). Also, the NPs exhibited excellent antioxidant and antimicrobial properties, prolonging the shelf life of the product. Moringa seed oil nanoemulsions obtained in a study of Abdelraouf et al. (2023) influenced the overrun values of ice cream positively, resulting in a softer texture and improving the whipping ability of the product.

Nanoemulsions (NEs) have nanoscale droplet sizes with larger surface area compared to conventional emulsions, providing superior emulsion stability, optical properties, taste and odor, bioavailability and shelf life. They are used as carrier systems for bioactive compounds such as antimicrobials, antioxidants, vitamins and minerals, flavours and pigments, and are formed by the use of novel technologies like high-pressure homogenization, ultrasound systems and microfluidization. NEs of eugenol and cinnamaldehyde were formed by Abdelhamid et al. (2023), integrated in yogurt and tested against the pathogen *Helicobacter pylori*. The NEs in the contaminated yogurts successfully reduced the pathogen count. Nanostructured lipid carrier system was achieved by the NE of conjugated linoleic acid and cocoa butter (Hashemi et al., 2020). The stable NE was used to fortify low-fat milk, without any remarkable oxidation. Also, the effect of NE of bay tree extract was used to protect the processed cheeses (Hussein et al., 2023). The cheeses were used to feed female Swiss albino mices for two weeks, and the NE of bay tree extract was found to reduce oxidative stress and inflammation in mices. Application of nano-sized emulsions with low-fat content had been successful in ice cream production (Silva et al., 2012). Also, Alfaro and colleagues (2015) found that NE of purple rice bran oil into frozen yogurts has increased the antioxidant activity and nutritional profile of the product. Moreover, NEs of curcumin in commercial milk provided significant antioxidant activity, resulting in a month of storage at ambient temperature (Joung et al., 2016).

Nanoencapsulation is used for the encapsulation of bioactive compounds, in order to protect them from environmental factors like temperature, pH, enzymes etc. during processing and storage, ensuring the extended quality and shelf life of dairy products, and also reducing food waste. This technology also offers the controlled release of these bioactive compounds during digestion, thus improving bioavailability. These bioactive compounds include probiotics, prebiotics, essential oils, bioactive peptides, vitamins, and minerals. Zhang and Zhong (2018) conducted a study for the nanoencapsulation of lactase with sodium caseinate and lecithin, and the hydrolysis of lactose in milk reduced from 75% to 15% for the encapsulated lactase. Tomato peel extract was encapsulated into zein and gelatin fibers by electrospinning method and used in yogurt (İnanç Horuz & Belibağlı, 2019). The encapsulated nanofibers increased the radical scavenging activity of the product. Also, Siyar et al. (2022) encapsulated saffron extract with soy lecithin, and used the nanoencapsulants in Ricotta cheese. In another study nanoliposomes were used for the encapsulation of garlic extract (Pinilla et al., 2017). The researchers found that these nanoencapsulants were effective for the inhibition of *Listeria* (*L*.) species in milk. Likewise, nanoliposomes containing nisin and garlic extract also controlled the growth of pathogens such as *Escherichia coli (E. coli), S. aureus*, *Salmonella enteritidis*, and *L. monocytogenes* in milk (Pinilla & Brandelli, 2016) and NEs containing curcumin inhibited *S. aureus* and *E. coli* growth in soft cheese (Bagale et al., 2023).

Improvement of sensory quality

Several nanotechnology methods have beneficial effects on sensory quality of milk and dairy products. Nanomaterials improve the sensory properties such as taste, aroma and texture by enhancing the stability, solubility, and functionality of milk components. For example, nanoencapsulants successfully cover up the unpleasant taste and flavour and helps the ensurance of sensory quality. NEs have positive effect on creaminess, mouthfeel and the overall acceptance of dairy products, thus influence the consumer preferences (Panghal et al 2019). Ghorbanzade et al. (2017) conducted a study about nanoencapsulation of fish oil in yogurt, and achieved good sensory scores for color, taste and texture for nano-liposomal samples compared to the free fish oil sample. Nanoencapsulated sample affected the overall acceptability in a positive way. Also, incorporation of hesperetin in solid lipid NPs into milk, brought successful

results of sensory evaluation that showed nanoencapsulation masked the bitter and aftertaste of hesperetin (Fathi et al., 2013).

Packaging of milk and dairy products

The most common use of nanotechnology in the dairy industry is the development of nanomaterials for active, smart and edible packaging systems. Especially antimicrobial paskagings prepared with NPs of antimicrobial compounds, essential oils, proteins and polysaccharides constitute the vast majority of the applications. These packaging materials were used especially in cheese preservation. Active food packaging strongly preserves food products by inhibiting pathogen growth, thereby extending the shelf life. In a study, gelatin nanofibers comprising moringa oil-loaded chitosan NPs were used in active packaging of cheese, where nanofibers showed great antibacterial activity against *S. aureus* and *L. monocytogenes* (Lin et al., 2019). In another study of Ligaj and friends (2020), polylactide films containing zero-valent iron showed good antimicrobial activity against *Bacillus subtilis*, *E. coli*, *Staphylococcus epidermidis*, thus extending the shelf life of goat cheese. Smart packaging can be described as a combination of active and intelligent packaging systems. These materials are engineered to respond to specific stimuli, such as changes in pH, temperature, moisture, gas levels, light exposure, enzyme activity, or chemical composition (Sani et al., 2021). For example, the effect of biobased smart packaging with pH-sensitive films based on anthocyanin from red cabbage and sepiolite mineral nano-clay was studided by Raji et al. (2022). Smart films changed the color from pink at pH lower than 6 to yellow at higher pH than 6 and were useful in milk. Also, intelligent films were developed with chitosan and eggplant extract for monitoring milk spoilage (Yong et al., 2019).

Among various packaging applications, edible coatings are innovative solutions for fresh and high nutritive foods and preferred as being safe. For example, an edible coating based on tapioca starch and glycerol containing natamycin and nisin was developed by for the treatment of Gouda cheese, providing a barrier against contamination (Berti et al., 2019). In a study of Silva and friends (2022), an edible coating with bacteriocin-producing *Lactococcus* strains were incorporated with alginate, maltodextrin and glycerol, and used for fresh cheese storage. The coating reduced moisture loss and contamination by *L.* monocytogenes.

Challenges of nanotechnology in dairy industry

Besides the advantages of nanotechnology, dairy industry also faces some challenges regarding the use of NPs and nanotechnological methods. The first challenge is the obligation of producing safe products for human consumption. Since almost all nano systems are designed by innovative and advanced methods, the production costs may still be expensive for the low profit dairy industry. Also, defining and eliminating the potential hazards and toxicity of the nano practices and minimizing the concerns about environmental issues are the challenges needed to be overcome. For the proliferation of nanotechnology utilization in dairy industry, the scientists, dairy industry stakeholders and regulators should work and act together.

CONCLUSION

Nanotechnology brings so many advantages to the dairy industry by influencing the raw material and product quality, facilitating the production processes, and achieving innovative and functional dairy products with enhanced health benefits. By overcoming the above-mentioned challenges, nanotechnological methods seem to take a larger place in dairy industry in the following decade.

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IOT-BASED PROTOTYPE FOR INDUSTRIAL EQUIPMENT MONITORING AND PREDICTIVE MAINTENANCE

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ABSTRACT
Over the past few years, a new technology has emerged in the field of electronics and computer networks, enabling the creation of systems connected to computer networks. This technology, known as the Internet of Things (IoT), has the potential to significantly enhance the growth of information and communication technologies (ICT) in urban environments. It also provides services that can greatly improve the well-being of individuals and Industrial companies. Therefore, this study aims to develop an IoT prototype for field equipment inspection and a mobile application for managing the dashboard of the methods office. To successfully accomplish this mission, we began with research on IoT technology (benchmarking), followed by the analysis and design of the prototype and the application. This study identified various areas, encompassing a thorough inspection of different characteristics and technical aspects.
Keywords: Industrial IoT; IoT design; Industry 4.0, predictive maintenance

Results and Interpretation

The implemented IoT prototype effectively measures key environmental and operational parameters such as temperature, pressure, humidity, and air quality. The system ensures real-time data visualization via a secure, locally accessible dashboard, supporting both monitoring and traceability. A historical database of sensor readings is maintained, creating a solid foundation for future AI-driven predictive maintenance strategies. In parallel, a mobile application was developed to extend dashboard functionalities to field operators and methods office staff. It enables real-time KPI tracking and supports key operational activities including planning, maintenance scheduling, spare parts tracking, and equipment lifecycle management. These results highlight the prototype's potential to streamline maintenance processes, enhance responsiveness, and support smart decision-making across industrial operations.

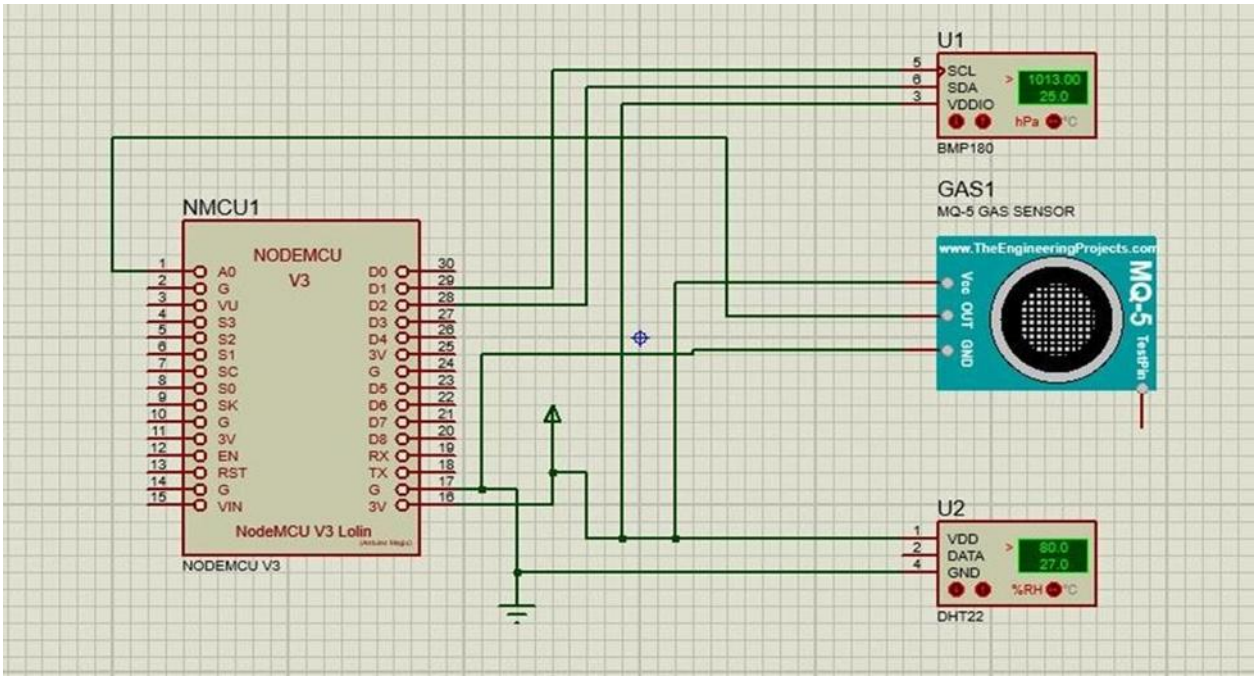

Figure 1: Connection Diagram of the Prototype

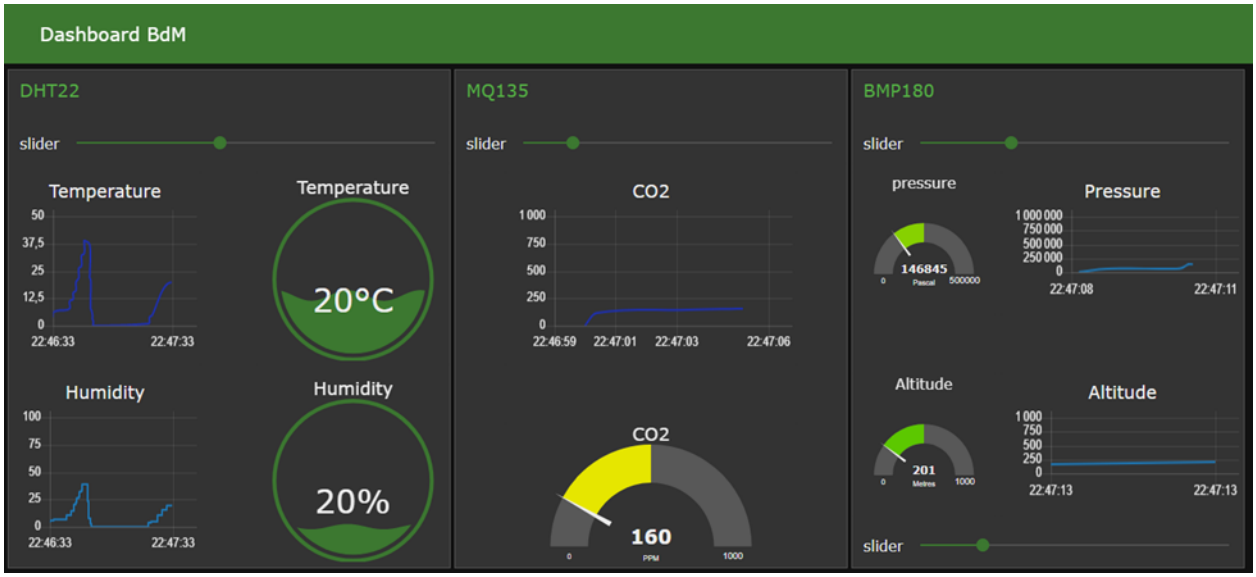

Figure 2 : The dashboard of measured quantities

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COMPARATIVE STUDY OF TITANATE-BASED PEROVSKITE OXIDES FOR ENERGY STORAGE DEVICES

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ABSTRACT
Titanium-based perovskite oxides were formed by sol-gel process using metal nitrates and titanium isopropoxide as starting materials. In this work, a comparison between the structural, chemical, optical, morphological, dielectric and electrochemical properties of various titanate-based perovskite oxides such as barium, strontium and calcium titanate is done. XRD confirmed the formation of perovskite structure in all the titanates. FTIR analysis and SEM are used to find the functional group and morphology of the samples, respectively. Uv-visible spectroscopy revealed that $CaTiO_3$ has the highest bandgap of 3.51 eV, which decreased sequentially in $SrTiO_3$ (3.24 eV) and $BaTiO_3$ (3.20 eV). Dielectric studies showed that $BaTiO_3$ has the highest dielectric constant of 1211 at room temperature, while $SrTiO_3$ and $CaTiO_3$ showed a lower value of 240 and 190, respectively, at the same frequency. The electrochemical studies of the prepared nanocomposites were assessed by cyclic voltammetry, galvanostatic charge-discharge and electrochemical impedance spectroscopy. In comparison to $SrTiO_3$ and $CaTiO_3$, which exhibit a specific capacitance about of 251 and 165 Fg^{-1}, $BaTiO_3$ exhibits a high specific capacitance of 436 Fg^{-1} at the scan rate of 1 mVs^{-1}. Also, the highest energy density of 16.76 $Whkg^{-1}$ for $BaTiO_3$ is recorded from galvanometric charge-discharge measurements. In addition, the prepared electrode serves as a better environmentally friendly candidate with comparatively high specific capacitance and energy density compared to lead-based oxides already used in the market for energy-related applications.
Keywords: Titanium-based perovskite oxides, sol-gel method, dielectric constant, specific capacitance.

1. INTRODUCTION

In last few Years enormous attempts have been put to form renewable energy such as energy from sun, ocean and wind as demand increases due to development of the civilization, the fossil fuel and other pollution issues because of high energy consumption. As the utilization of fossil fuel has led to a rise in pollution and environmental degradation. Thus, renewable energy helps in the reduction of environmental pollution which can be done by nonrenewable energy resources. But first there is a need to store this harvested energy by means of some energy storage devices and then applied to electrical equipment's for further use. As a result, there has been a huge demand of energy storage appliances including chemical batteries, fuel cells, electrochemical hybrid supercapacitors and high dielectric capacitors [1, 2].

Among these choices supercapacitors also referred as electrochemical capacitors are a type of rechargeable energy storage device that fills the gap between conventional batteries and capacitors. They possess high power density and moderate energy density. These properties make them suitable for a wide range of energy storage applications. Typically, supercapacitors are available in two different kinds namely electric double layer capacitors EDLCs and pseudocapacitors [3].

On the other hand, dielectric capacitors assure to be used in super high-power electronics like hybrid electronic automobiles, satellites, electrical weapon systems and spacecraft due to their significantly higher power density. Despite of the fact that batteries have many applications in electrical devices but their low power density and unstable cyclic process restrict their trade on higher scale [4]. On the other hand, dielectric capacitors meet twenty-five percent of our weight and volume of power electronics. But they have low energy density. As one of the important properties for evaluating the energy storage capacity of a dielectric capacitor is the energy storage density. It is necessary to form new dielectric materials as well as stable electrodes with high electrochemical properties such as high specific capacitance and energy density that can be used for energy storage applications [2].

In this regards many lead-based materials are already used [5]. But these lead-based materials have disadvantage that they pollute the environment. There is a need to develop lead-free environment friendly materials with improved energy storage properties. For decades scientists have fascinated by perovskites materials because of their appealing ferroelectric, dielectric, piezoelectric and catalytic capabilities. These materials are important for many future technical applications. Currently Lead-free, Titanium-based perovskite oxides are being investigated for energy storage applications in order to resolve environmental issues.

Titanium-based perovskite oxides ($ATiO_3$) belong to ternary metal oxide compounds. They are multi metal oxides which have two metal cations of different size [6]. These metallic cations are surrounded by anions like oxygen for example barium, strontium and calcium titanate have been attract the attention of many scientists in various fields which includes dielectrics, supercapacitors and catalysts. This is because of their diverse properties like high dielectric constant, high specific capacity and specific catalytic activity.

The titanium-based perovskite oxides can be made using a number of techniques like combustion process [7], solid state method [8], sol gel [9], hydrothermal [10] and co-precipitation method [11]. These techniques can produce a variety of material structures and the choice of method will rely on the necessary structural morphology, chemistry, fabrication as well as the cost of associated materials. The preparation method that works best for real-world energy storage application should be enough able to manufacture nanomaterials with high energy density at low cost.

Solid state reaction method produces metal titanate oxides with impure phase thus to produce single phase barium, strontium and calcium titanates sol-gel method was used. Also, sol gel method produces metal titanate oxides at relatively low temperature as compared to

solid state reaction method. These metal titanate oxides have perovskite structure and are widely used in devices to store energy due to their excellent dielectric and electrochemical properties. Because of its enormous technological uses production of high-quality nanoparticles with refine dielectric and electrochemical properties is crucial in advanced ceramic research [12].

Although numerous relevant works have been published up to this point but there is currently no compressive evaluation on the present state in free of lead dielectric materials that can be used for energy storage. Also, in many of the previous work preparation and other properties of various titanates have been mentioned but there is no comparative work published yet which gives a comparison of various properties specially the dielectric and electrochemical properties of these pure titanate ($SrTiO_3$, $BaTiO_3$ and $CaTiO_3$). Therefore, in this study a structural, dielectric and electrochemical comparison of various titanate-based perovskite oxides have been mentioned in order to give them a direction to use in energy storage applications.

2. MATERIALS AND METHOD

For the synthesis of $SrTiO_3$, $BaTiO_3$ and $CaTiO_3$, Strontium nitrate [$Sr(No_3)_3.6H_2O$], Barium nitrate [$Ba(No_3)_3.6H_2O$] and Calcium nitrate [$Ca(No_3)_3.6H_2O$] were used as precursor for the source of Strontium, Barium and Calcium respectively. Nitrates of these metals were chosen as precursors because metal nitrate produces single phase crystal structures at low temperature as compared to metal acetates which requires high temperature also can lead to impure phases [13]. While titanium isopropoxide $Ti[O(C_3H_7)]_4$ was used as source of titanium because this titanium alkoxide makes the nucleophilic attack of the metal possible as it is highly reactive [9]. Other reagents such as nitric acid and acetic acid were also used to facilitate the chemical reaction.

For the production of $SrTiO_3$, $BaTiO_3$ and $CaTiO_3$ by sol gel method, a suitable amount of Strontium nitrate [$Sr(No_3)_3.6H_2O$], Barium nitrate [$Ba(No_3)_3.6H_2O$] and Calcium nitrate [$Ca(No_3)_3.6H_2O$] respectively were added in 100 ml of distilled water separately and stirred till homogenous solutions formed. Then 6ml of titanium isopropoxide $Ti[O(C_3H_7)]_4$ was added drop wise in each solution, the white precipitates were formed instantly. Stirred the above solutions also add 1.2 mL of nitric acid HNO_3 and 16 mL of acetic acid CH_3COOH in the above solutions. The mixtures were then stirred for five hours maintaining the temperature at sixty degrees centigrade. The resulting semi-transparent suspension solution was evaporated at 80 °C. The resulted powder was dried at hundred degrees centigrade for 6 h to obtained the final product [14].

3. RESULTS AND DISCUSSION

3.1. Microstructure Analysis

XRD analysis of various titanate-based perovskite oxides is shown in the Figure 1. below. Result shows that $SrTiO_3$ has cubic perovskite structure while $BaTiO_3$ has tetragonal and $CaTiO_3$ has orthorhombic perovskite-like crystal structure. The XRD patterns of $BaTiO_3$, $SrTiO_3$ and $CaTiO_3$ are well matches with JCPDS numbers 79-2264, 35-0734 and 22-153 respectively. Cubic crystal structure is considered as the ideal perovskite structure so in order to find the deviation of $BaTiO_3$ and $CaTiO_3$ from ideal perovskite structure Goldschmidt tolerance factor is calculated using formula [15]

$$t = \frac{r_A + r_o}{\sqrt{2}(r_{B+} r_o)} \qquad (1)$$

where r_A is the radius of A cation, r_B is the radius of B site cation and r_o is the radius of oxygen anion. Both peak shift and change of peak intensities are observed with change of A-site cation. According to [16] peak shift may be appeared due to the smaller ionic radius of Sr^{2+} (1.44 Å) and Ca^{2+} (1.34 Å) ions as compared to Ba^{2+} ions (1.61 Å). Generally, atomic radius decreases form bottom to top (from barium to calcium) causes the lattice parameters of $SrTiO_3$ and

$CaTiO_3$ to be decreased as compared to $BaTiO_3$ which in turn gradually decreases the lattice volume of $SrTiO_3$ and $CaTiO_3$.

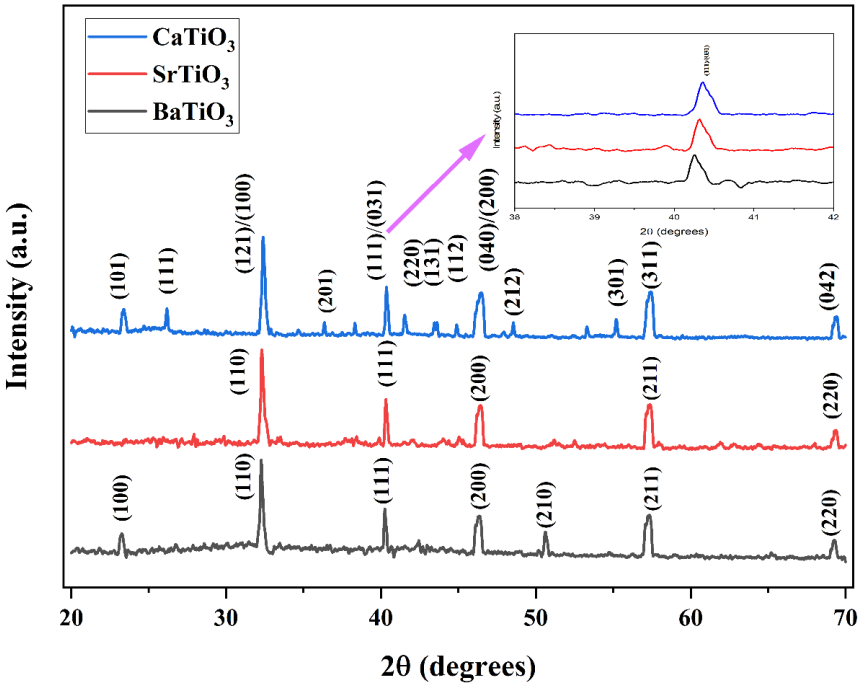


Figure 1. The XRD pattern of $BaTiO_3$, $SrTiO_3$ and $CaTiO_3$ respectively. Also, it presents a zoom of (111) peak.

Also, the decrease in lattice parameters from $BaTiO_3$ to $CaTiO_3$ causes the decrease in d-spacing which shift the peaks towards the higher order according to Bragg's law [17]

$$2d_{hkl} \sin(\theta) = n\lambda \qquad (2)$$

Where d is the interplanar spacing. $BaTiO_3$ has the largest crystalline size which gradually decreases in $SrTiO_3$ and then further in $CaTiO_3$. The values of lattice parameter, d-spacing, tolerance factor and crystalline size for 110 plane are shown in the table 1. The crystalline size is calculated using Scherrer formula [18]

$$D = K\lambda / (\beta \cos\theta) \qquad (3)$$

Where D is the crystalline size, λ is the wavelength of x-rays (λ = 1.54178Å) for Cu k_{α}, while β is the full width half maximum.

Table 1. Results obtained from the XRD data of $BaTiO_3$, $SrTiO_3$ and $CaTiO_3$ measured at room temperature.

Sample	Space group	Lattice parameter a (Å)	Lattice parameter b (Å)	Lattice parameter c (Å)	Average crystallite size (nm)	d-spacing (nm)	Tolerance factor t
$BaTiO_3$	P4mm	3.97	3.97	4.03	97.52	0.280	1.06
$SrTiO_3$	$Pm\bar{3}m$	3.91	3.91	3.91	28.30	0.275	1.001
$CaTiO_3$	Pbnm	5.44	7.61	5.37	24.49	0.273	0.966

3.2. SEM Analysis

The morphology of the examined titanate-based perovskite oxides is shown in the figure 2. It provides visual evidence that $BaTiO_3$ and $SrTiO_3$ particles are round in shape having unform distribution with sizes in nano-meter range. While $CaTiO_3$ did not show any specific shape with agglomerated particles in nanometer size range. The particle size measured for $BaTiO_3$ from the SEM image 2. (a) is found to be 81 nm. This suggests that nanocrystalline particles are formed when titanates-based perovskites ($BaTiO_3$, $SrTiO_3$ and $CaTiO_3$) are formed by sol-gel method [19]. However, not any of the titanate oxide is monodispersed. Furthermore, the SEM images show that $BaTiO_3$ has a smooth surface morphology whereas the surface roughness increased for $SrTiO_3$ and $CaTiO_3$ samples.

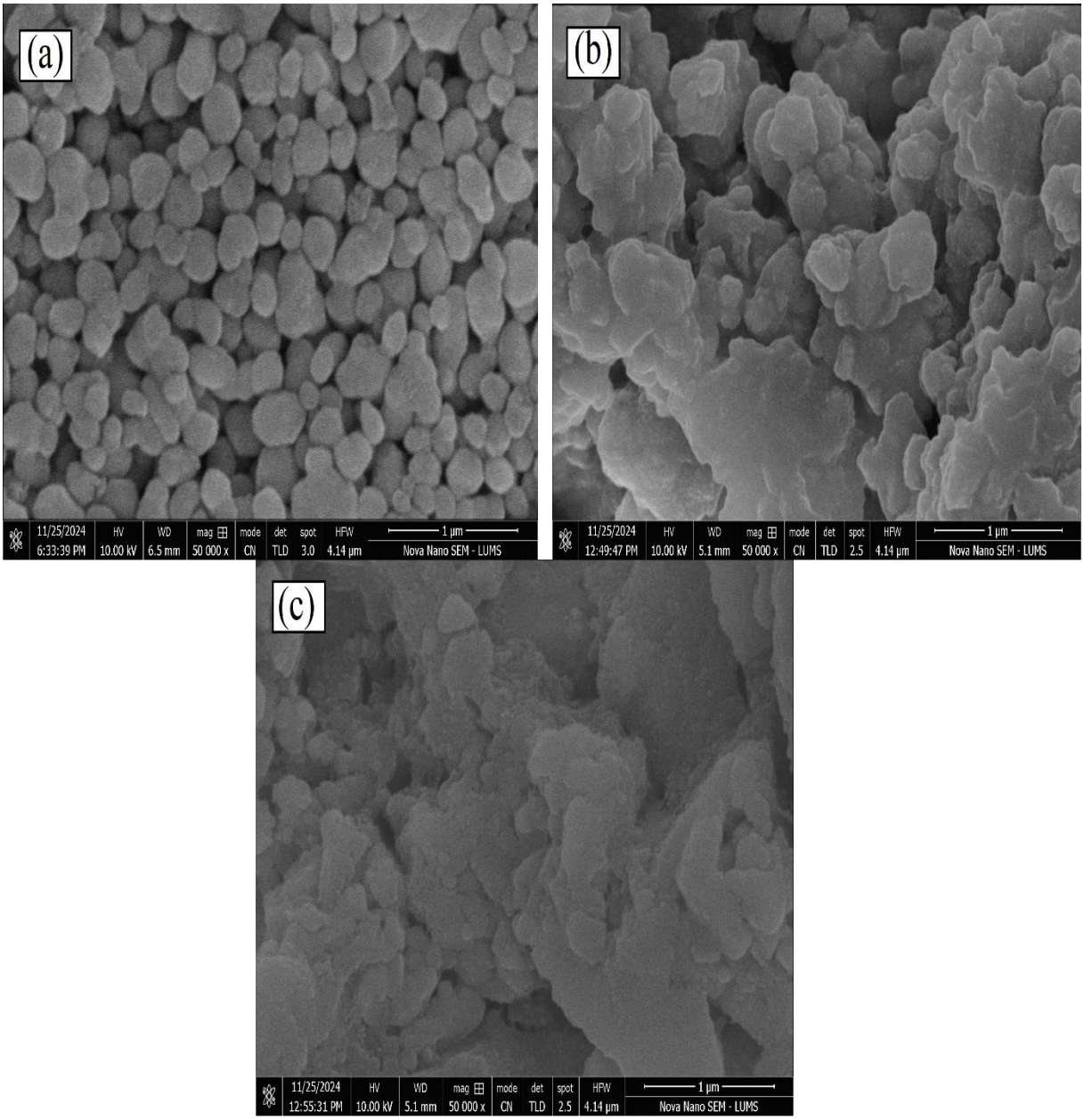


Figure 2. SEM image of (a) $BaTiO_3$, (b) $SrTiO_3$ and (c) $CaTiO_3$ respectively.

3.3. FTIR Analysis

The FTIR analysis of the examined titanate-based perovskite oxides is used to find the organic compounds found in the under examined species and is shown in the figure 3. As it is already known that the absorption bands in the range of 1085-1050 cm^{-1} belongs to the C-O group. The peaks appear in this range in all the three samples corresponds to C-O stretching which is the characteristic peak of titanium isopropoxide, a precursor of sol [20]. Moreover, a strong peak is observed in all the examined samples at about 1311 cm^{-1} indicating NO_2 stretching due to the use of metal nitrates as precursor [21].

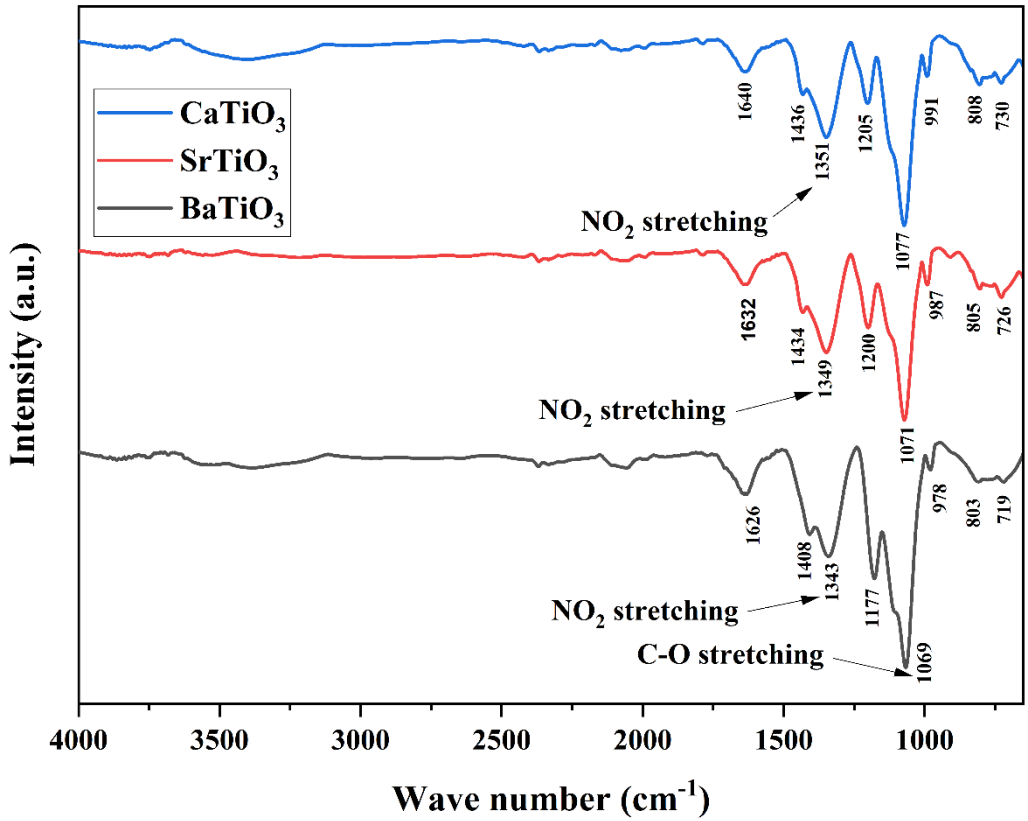


Figure 3. The FTIR spectrum of prepared $BaTiO_3$, $SrTiO_3$ and $CaTiO_3$ respectively.

The peak observed at 803 cm^{-1} in the FTIR spectra of first compound while 726 cm^{-1} in the FTIR spectra of second compound and the peak appeared at 730 cm^{-1} in the FTIR spectra of third compound indicates the stretching of oxygen metal [9, 21, 22].

3.4. UV- Visible Spectroscopic Analysis

The optical absorbance of titanate-based perovskite oxides in 200-700 nm range is shown in the figure 4. From the absorbance plot it is clear that the absorbance edge value of $BaTiO_3$ is 389 nm while for $SrTiO_3$ and $CaTiO_3$ it is 384 nm and 357 nm respectively which is according with the previous reported data [23]. This can be justified in terms of ionic size. The large ionic size of Ba^{2+} as compared to Sr^{2+} and Ca^{2+} causes weak overlapping and more delocalization of electrons thus they required less energy to move from valance band to conduction band results in low band gap and high corresponding absorbance edge wavelength. From fig. 4. (a) It can be seen that $\lambda_{BaTiO3} > \lambda_{SrTiO3} > \lambda_{CaTiO3.}$

Table 2. bandgap and absorbance edge measurements of $BaTiO_3$, $SrTiO_3$ and $CaTiO_3$

Material	Energy Bandgap (eV)	Absorbance edge wavelength (nm)
$BaTiO_3$	3.20	389
$SrTiO_3$	3.24	384
$CaTiO_3$	3.51	357

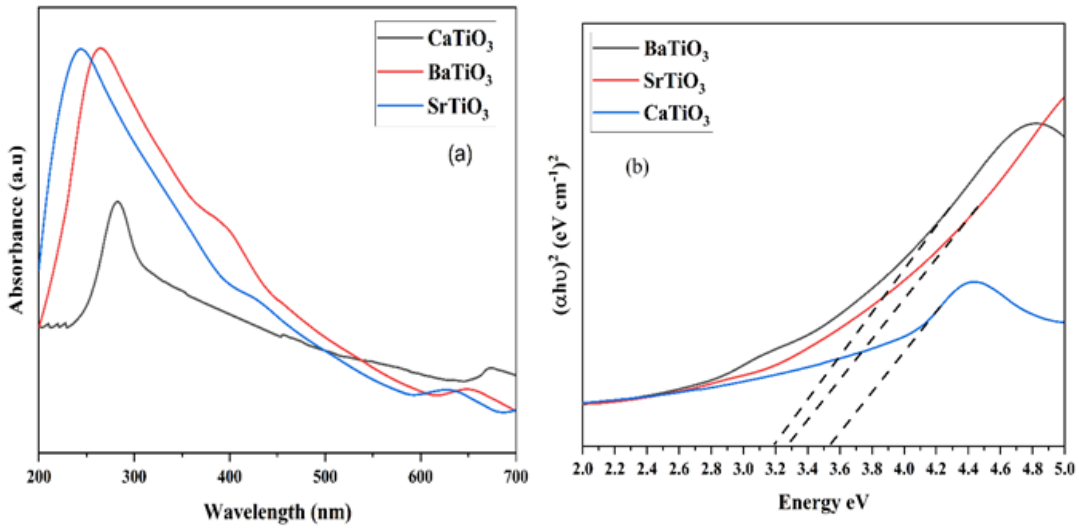


Figure 4. UV- Visible spectroscopic (a) absorbance and (b)Tauc plots

The bandgap energy of the material is related to wavelength as [24]

$$Eg = \frac{1240}{\lambda\ (nm)}\ \text{eV} \qquad (4)$$

Thus, the energy bandgap varies from 3.20 eV to 3.51 eV as moves from $BaTiO_3$ to $CaTiO_3$. The energy bandgap values of various titanate-based perovskite oxides are given in the table 2.

3.5. Dielectric Analysis

The temperature dependent dielectric constant for specific values of frequency in the range 1k Hz to 100k Hz is shown in figure 5. From Figure 5. (a) it can be seen that at the specific frequency of 1k Hz, $BaTiO_3$ has the highest dielectric constant of about 1211 at room temperature ~25 °C (~298K) as compared to $SrTiO_3$ and $CaTiO_3$ which has the dielectric constant of about 240 and 190 at the same frequency as shown in Figure 5. (b) and (c). Also, in $BaTiO_3$ dielectric constant increases as temperature increases up to its curie temperature while further increase in temperature reduces its values due to change of phase from ferromagnetism to paramagnetism [9]. On the other hand, in $SrTiO_3$ dielectric constant decreases as temperature increases up to a certain value and then begin to increase as temperature increases. This is may be because of increase of polarizability with the increase of thermal vibrations as temperature increases [25]. While in CaTiO3 dielectric constant decreases as temperature increases and has the maximum value at room temperature. This is may be due to more prominent effect of

thermal fluctuations which decreases polarization [26, 27]. These results are also consistent with the fact that BaTiO3 shows ferromagnetic behavior at room temperature while SrTiO3 and CaTiO3 shows paramagnetic at room temperature.

In BaTiO3 dielectric loss increases as temperature increases for all the frequencies till 120 °C (~ 393k) then begin to decrease with further rise in temperature as shown in Figure 6. (a). On the other hand, in SrTiO3 the value of dielectric loss remains low till 350K and then begins to increase rapidly with more increase of temperature for all frequencies as shown in Figure 6. (b). While it can be seen from Figure 6. (c) that in CaTiO3 as the temperature increases the dielectric loss also increases for all frequencies suggesting that CaTiO3 is a lossy material. Also, at lower frequency there is less fluctuation in dielectric loss while as frequency increases the fluctuations in dielectric loss becomes more prominent [26].

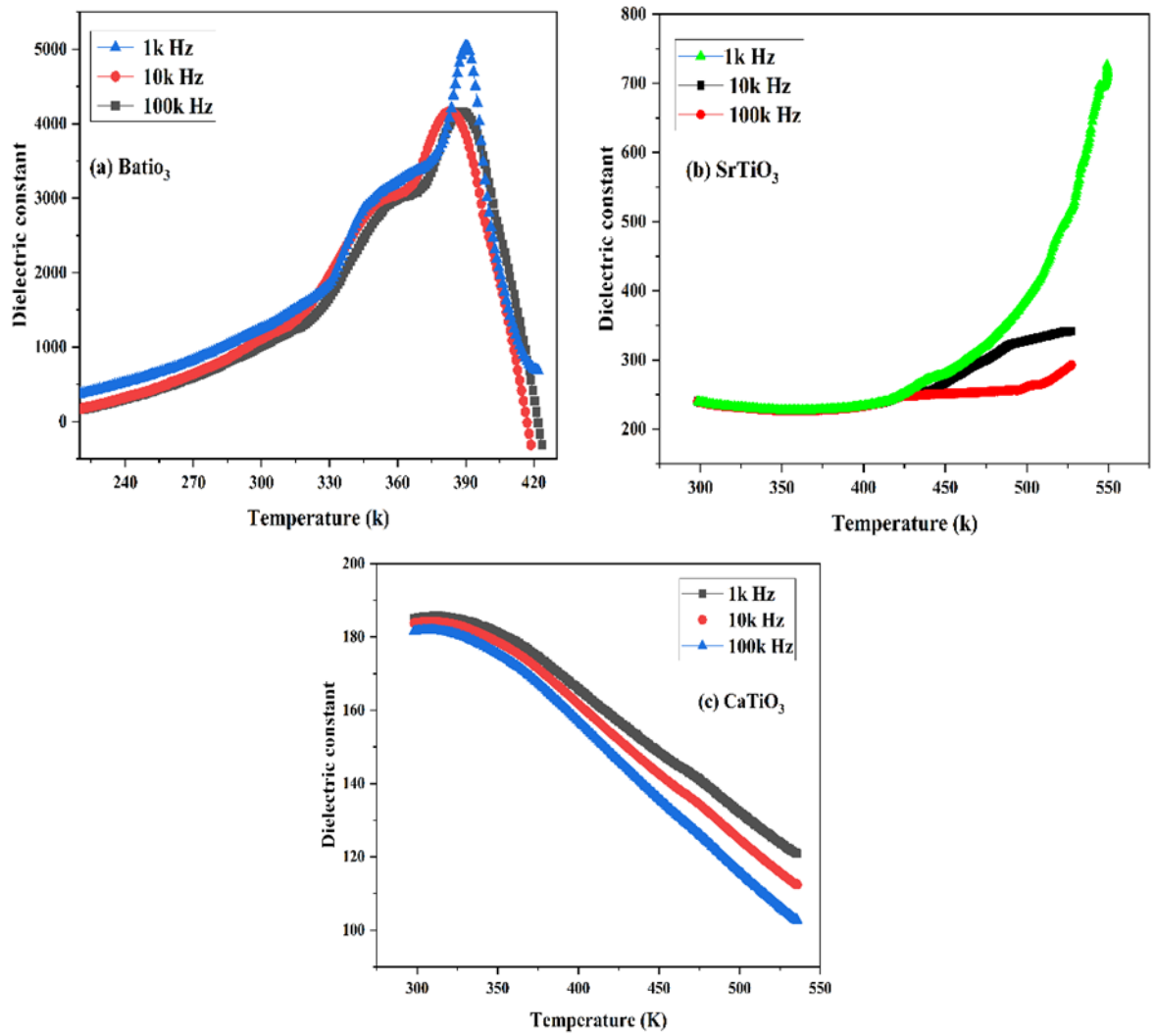


Figure 5. Temperature dependent Dielectric constant of (a) $BaTiO_3$, (b) $SrTiO_3$ and (c) $CaTiO_3$ respectively.

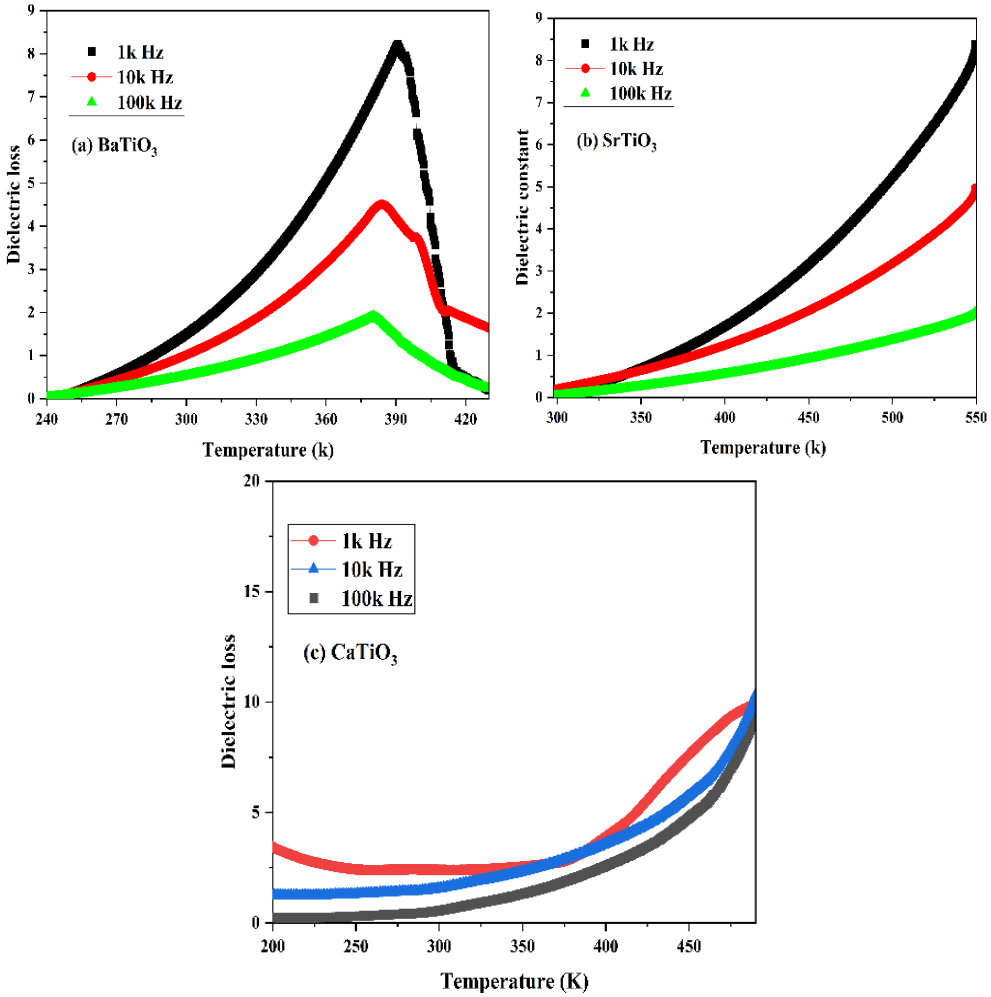


Figure 6. Temperature dependent Dielectric loss of (a) $BaTiO_3$, (b) $SrTiO_3$ and (c) $CaTiO_3$ respectively.

3.6. Electrochemical Analysis

Cyclic voltammetry analysis was carried out for $BaTiO_3$, $SrTiO_3$ and $CaTiO_3$ nanoparticles-based electrode on nickel mesh as an electrochemical electrode in a three-electrode set up with 1 M KOH solution and Ag/AgCl serving as the reference electrode to examine the charge storage on the electrode surface and electrochemical performance. As shown in Figure 7 (a), (b) and (c), CV curves of the synthesized materials at the scan rate in the range from 1 to 50 mV/s shows pronounced anodic-cathodic peaks because of the electrolyte absorption on the surface of electrode and the electrolyte interaction with the ionic species of electrode during the reversible CV process. The charge storage via pseudocapacitive mechanism is shown by the quasi-rectangular voltammograms of all the synthesized electrodes which deviates from the ideal EDLC behavior (rectangular shape). According to literature review, the double-layer capacitor's shortcoming is addressed by pseudocapacitors. Because pseudocapacitors store charge through both faradic and non-faradic processes as they can maintain a higher charge than double-layer capacitors [28].

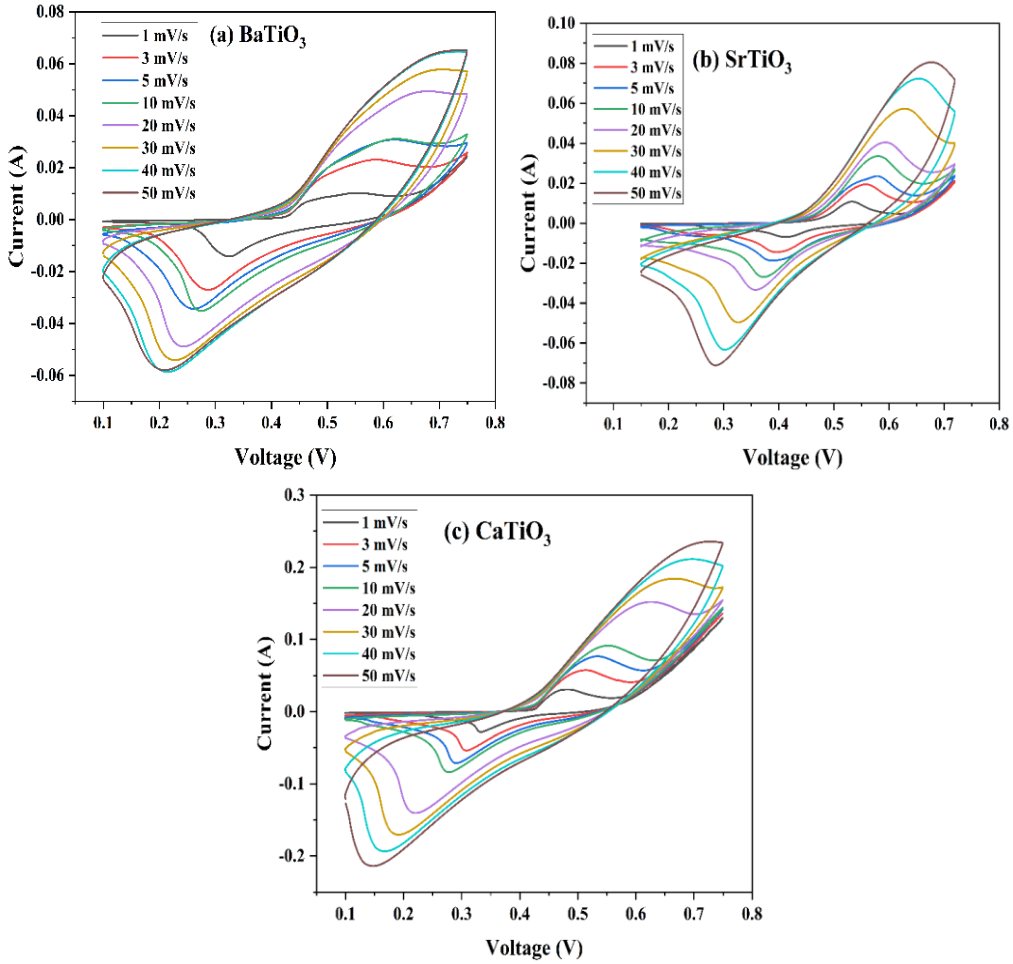


Figure 7. Cyclic voltammetry curves at different scan rates for (a) $BaTiO_3$, (b) $SrTiO_3$ and (c) $CaTiO_3$ respectively.

Furthermore, the capacitance property and kinetic reaction of $BaTiO_3$, $SrTiO_3$ and $CaTiO_3$ are measured at different scan rates suggest that as the scan rate increases area under the curves increases while specific capacitance decreases for all the prepared electrodes. Also, as the scan rate increases the ions in the electrolyte do not get enough time to diffuse into the surface host sites consequently the specific capacitance decreases [29]. But as the current is proportional to the scan rate, the current density increases with the increase of scan rate. Furthermore, at high scan rate the specific capacitance decreases because the active species are unable to maintain intercalation on the electrode surface. The power law provided by the following equation given below can be used to match the CV curves in order to understand the electrochemical charge storage mechanism [30]

$$i_p = \alpha V^b \qquad (5)$$

Where i_p shows peak current, V stands for scan rate, and α and b are adjustable parameters. The b value can be determined by calculating the slope of the log i_p Vs. log V graph. The above relationship can be used to calcite the capacitive or diffusive contributions. If the b-value is nearer to 0.5, the capacitive response is more likely to be diffusion dominated (behaves like a battery. If the b-value is nearer to 1, the electrodes surface responses are more likely capacitive dominated. The b-values of $BaTiO_3$, $SrTiO_3$ and $CaTiO_3$ obtained are 0.67, 0.81 and 0.84 respectively. As the values of all the prepared titanates are closer to 1 showing that the charge storage mechanism is dominated by capacitive response at low voltage regime. Moreover, from the Figure 8. (a), (b) and (c) it can be seen that as the sweep rate increases from 1 to 50 mVs^{-1} the specific capacitance of all the prepared electrodes ($BaTiO_3$, $SrTiO_3$ and

$CaTiO_3$) decreases which is may be due to less ion diffusion at the interface between electrode and electrolyte as the sweep rate increases. This implies that the internal surface of all the material electrodes is unable to support the redox transition and only the outer surface is active for storing charges [31].

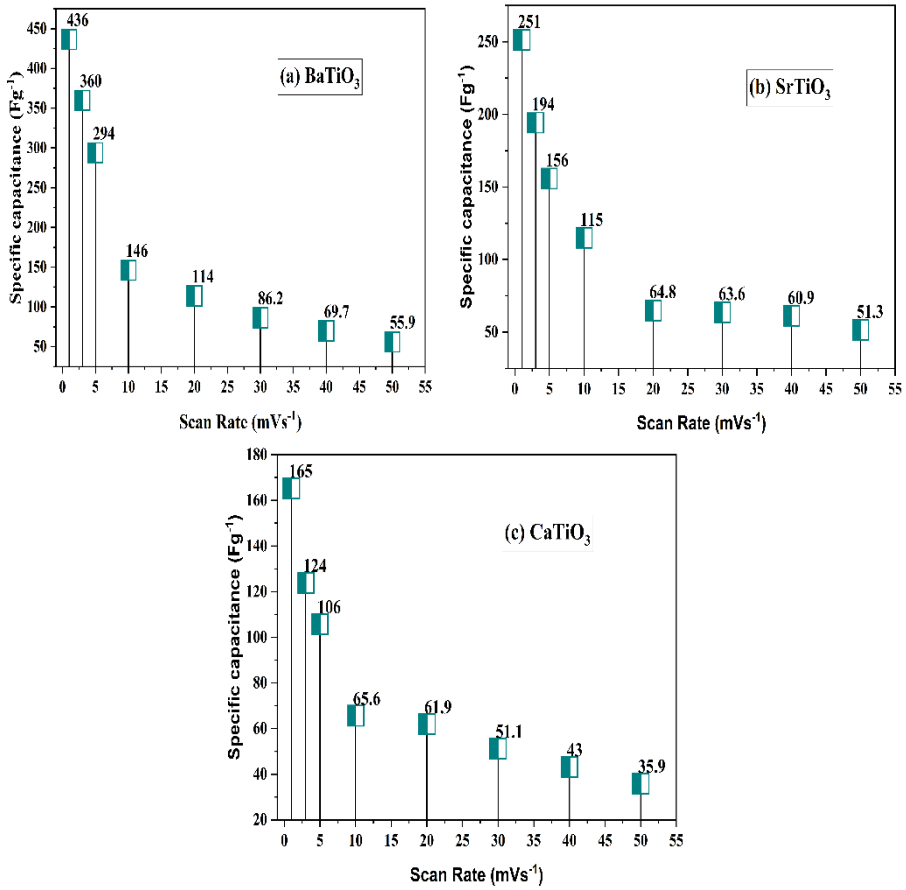


Figure 8. Specific capacitance Vs. scan rate for (a) $BaTiO_3$, (b) $SrTiO_3$ and (c) $CaTiO_3$ respectively.

The galvanostatic charge-discharge properties of $BaTiO_3$, $SrTiO_3$ and $CaTiO_3$ nanoparticles-based electrodes were investigated in 1 M KOH electrolyte and at different current densities as shown in Figure 9. (a), (b) and (c). The capacitor cyclic stability is crucial for real-world applications. Galvanostatic charge-discharge measurements at different current densities (0.408, 0.612, 0.816, 1.00, 1.224 and 1.428 A/g) with cut off voltage ranging from 0.1 to 0.8 V were used to investigate the stabilities of $BaTiO_3$, $SrTiO_3$ and $CaTiO_3$ nanocomposites. From Figure 9. (a) $BaTiO_3$ shows a better discharge time than $SrTiO_3$ and $CaTiO_3$ electrodes at all current densities. According to the non-linear potential-time response behavior, these figures demonstrate that the synthesized electrodes charging and discharging processes are reversible which

Table 3. Comparison of specific capacitance values of current work with reported literature.

Material	Electrolyte	Current density/ Scan rate	Potential range (V)	Specific capacitance (Fg^{-1})	Ref.
$BaTiO_3$	1 M KOH	0.408 Ag^{-1}	0.1-0.8	397	This work
$SrTiO_3$	1 M KOH	0.408 Ag^{-1}	0.1-0.8	222	This work
$CaTiO_3$	1 M KOH	0.408 Ag^{-1}	0.1-0.8	121	This work
PbO_2/AC hybrid	5.5 M H_2SO_4	0.2 Ag^{-1}	0.8-1.8	71.5	[32]
PbO_2/AC hybrid	5.3 M H_2SO_4	0.15 Ag^{-1}	0.65-1.88	63.2	[33]
PbO_2/ SnO_2	1 M H_2SO_4	25 mVs^{-1}	1.2-1.8	208	[34]
C/ PbO_2	1 M Na_2SO_4	1 mVs^{-1}	0.6-2.3	38	[35]

is according with the CV graphs. Additionally, the nonlinearity ensures that the capacitive nature of electrode is due to their pseudo-capacitance. An obvious sign of a pseudo-capacitive charge storage mechanism occurring within the material is its deviation from the usual triangular capacitor curves. The specific capacitance, energy density and power density of the synthesized materials were calculated by using the following formulas [36]:

$$C_s = \frac{I\,\Delta t}{m\,\Delta V} \quad (6)$$

$$E = \frac{0.5 \times C_s \times (V_{max}^2 - V_{min}^2)}{3.6} \quad (7)$$

$$P = \frac{3600 \times E}{T} \quad (8)$$

Where m stands for active mass, I stand for current density (A), **Δ**V for applied voltage and Δt shows the discharge time (s). By using Eq. (6) specific capacitance values of $BaTiO_3$, $SrTiO_3$ and $CaTiO_3$ are measured and are found to be 397, 222 and 121 Fg^{-1} respectively at 0.408 A g^{-1}. From the above results it is clear that $BaTiO_3$ has the highest value of specific capacitance compared to $SrTiO_3$ and $CaTiO_3$ electrodes. Also, $BaTiO_3$ indicated significantly greater value of specific capacitance in comparison to PbO_2 based earlier research findings as given in table 3. These results show that the electrode made from $BaTiO_3$ nanocomposites performed better among all these prepared electrodes.

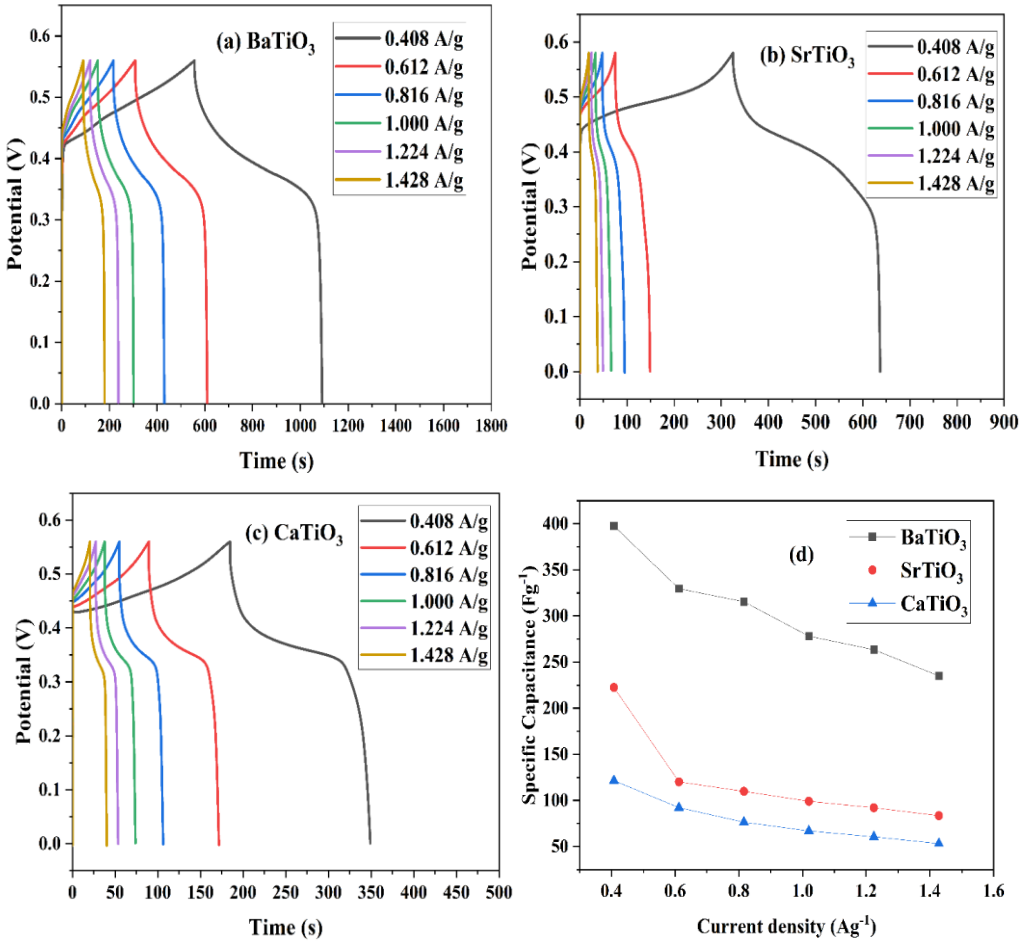


Figure 9. GCD curves at different current densities for (a) $BaTiO_3$, (b) $SrTiO_3$ and (c) $CaTiO_3$ respectively.

(d) Specific capacitance values at different scan rate for all the prepared electrodes.
The Figure 9. (d) shows specific capacitance of the synthesized electrodes at different current densities. Interestingly, a decrease in specific capacitance is linked with an increase in current density. This could be due to electrolyte ions have a short time to penetrate deeply into the electrode pores. A significant accumulation of charges on the porous surface is made possible by the slower charging process at lower current densities. Nevertheless, ions travel faster at greater current densities which shortens the time it takes for charges to accumulate on the porous surface and eventually lowers the specifics capacitance. Also, the values of energy density and power density for all the prepared electrodes are given in the table 4.

Table 4. Electrochemical parameters of $BaTiO_3$, $SrTiO_3$ and $CaTiO_3$ nanocomposites.

Material	Specific Capacitance (Fg^{-1})	Energy density ($Whkg^{-1}$)	Power density (Wk
$BaTiO_3$	397	16.76	112
$SrTiO_3$	222	10.14	116
$CaTiO_3$	121	5.04	111

Electrochemical impedance spectroscopy (EIS) was used to support the previous findings on all the prepared samples and results were analyzed using Nyquist plot as shown in Figure 10. The properties and efficiency of the electroactive material are mostly determined by the charge-transfer kinetics, internal resistance and pseudo-capacitance. The purpose of EIS investigations was to find key characteristics such as equivalent series resistance (ESR) and charge transfer resistance $R_{ct.}$ It can be seen that these Nyquist plots in a low frequency region show deviation from semicircle indicating the pseudo-capacitive behavior of composites which may because of large charge storage contact at electrolyte/electrode interface [37]. The best pseudo-capacitive behavior is indicated by the small equivalent series resistance (ESR) measurements for nanocomposite electrodes made of $BaTiO_3$, $SrTiO_3$ and $CaTiO_3$ are given in Table 5.

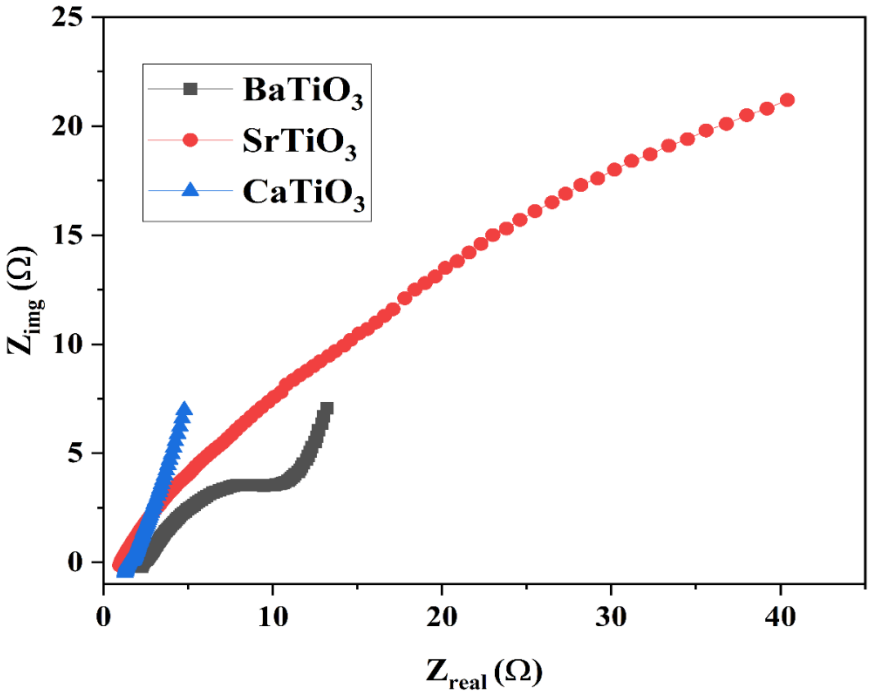
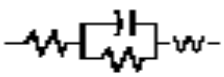


Figure 10. Nyquist plots for $BaTiO_3$, $SrTiO_3$ and $CaTiO_3$ nanocomposites.

Table 5. Equivalent series resistance and Equivalent circuit of $BaTiO_3$, $SrTiO_3$ and $CaTiO_3$ nanocomposites.

Material	**Equivalent series resistance ESR (Ω)**	**Equivalent circuit of EIS Spectrum**
$BaTiO_3$	2.25	
$SrTiO_3$	1.27	
$CaTiO_3$	0.95	

4. CONCLUSION

Titanium-based perovskite oxides ($BaTiO_3$, $SrTiO_3$, $CaTiO_3$) were produced using sol-gel method in which $SrTiO_3$ has cubic while $BaTiO_3$ and $CaTiO_3$ exhibit tetragonal and orthorhombic crystal structure respectively. X-ray diffraction confirmed the formation of single-phase nanostructures with $BaTiO_3$ having the largest crystalline size of 97.52 nm which decreases in $SrTiO_3$ (28.30 nm) and further decrease in $CaTiO_3$ (24.49 nm). Scanning electron microscopy indicated spherical shaped particle formation in $BaTiO_3$ and $SrTiO_3$ while $CaTiO_3$ did not show any specific shape. Uv-Visible spectroscopy revealed that $CaTiO_3$ has the highest energy bandgap of about 3.51 eV which decreased gradually in $SrTiO_3$ (3.24 eV) and $BaTiO_3$ (3.20 eV). Dielectric studies of the samples demonstrated that $BaTiO_3$ exhibits the highest dielectric constant of 1211 at room temperature while its value decreased in $SrTiO_3$ (240) and $CaTiO_3$ (190) at the same frequency. CV, EIS and GCD studies were used to examine the electrochemical characteristics of the prepared electrodes. $BaTiO_3$ electrode showed maximum specific capacitance of 436 Fg^{-1} as compared to $SrTiO_3$ and $CaTiO_3$ which showed a specific capacitance of 251 and 165 Fg^{-1} at the scan rate of 1 mVs^{-1}. The $BaTiO_3$ nanocomposites showed maximum energy density and power density as determined by galvanostatic charge-discharge studies were 16.76 $Whkg^{-1}$ and 112 Wkg^{-1} respectively with the specific capacitance value of 397 Fg^{-1} at 0.408 Ag^{-1} current density and has lower ESR value of 2.25 Ω. Additionally, $BaTiO_3$ nanoparticles offer more benefits as it showed high specific capacitance and energy density than other lead dioxide based nanocomposites already in use for this purpose due to their low cost and non-hazardous nature.

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DESIGN AND ANALYSIS OF MICROSTRIP PATCH ANTENNA USING TWO FEEDING METHODS FOR 5G APPLICATIONS

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ABSTRACT
Microstrip patch antenna is one of the most utilized antennas for several 5G applications because of its high radiation performance. This work proposes the design and simulation of a rectangular microstrip patch antenna having a compact size of 11.2×8.75 mm^2 resonating at 28 GHz. Two feeding methods (inset and gap-coupled) are compared to investigate the radiation performance of the antenna, particularly antenna loss and gain. The substrate is composed of Flame Retardant-4 (FR-4), featuring a dielectric constant of 4.3, a thickness of 0.699 mm, and a loss tangent of 0.025. Using Computer Simulation Technology (CST), the results showed that the reflection coefficient of -35 dB for the coupled-fed patch and -19 dB for the inset-fed patch antenna over a frequency of 28 GHz. The coupled-fed patch achieves a -10dB frequency bandwidth of 2.3 GHz while the inset-fed obtains 2 GHz. Both types of feeding are capable of covering the whole 5G band (27.5–28.35) GHz and satisfy the requirement of 5G. In addition, the far-field results reveal a gain of 6.7 dBi and 5.8 dBi for the coupled-fed patch and inset-fed patch, respectively. The results reveal that the coupled-fed microstrip antenna shows higher gain and lower return loss, which makes it more appropriate for applications of the 5G.
Keywords: Gain, 5G, millimeter wave, 28 GHz, microstrip patch antenna, feeding

1. INTRODUCTION

The field of antenna design has always presented difficulties in creating antennas that can work in 5G frequency bands. The millimeter wave radio spectrum is a frequency band utilized by 5G technology that can transmit vast amounts of data over short distances. The communication capacity is greatly increased by 5G technology. This invention increased the demand for novel antenna designs with low-profile and high-gain properties to ensure reliability and efficiency in wireless communication systems. Microstrip patches are the most suitable type of antenna to meet this demand due to their lightweight, ease of production, and simple feeding characteristics [1, 2].

This study proposes a microstrip antenna design using two feeding techniques: inset feed and coupled feed. For this design, FR4 substrate material with 0.699 mm thickness is used. The radiation characteristics of the proposed antenna are examined using (CST) simulation tool. The simulation results of both feeding methods are compared according to the best radiation performance suitable for 5G millimeter-wave applications.

2. DESIGN OF THE MICROSTRIP ANTENNA

The design equations of the patch are calculated at the operating frequency (f), substrate height (h), and the substrate's relative permittivity (ϵ_r). The patch width is given by [3-7],

$$W(\text{width of the patch}) = \frac{C}{2f}\sqrt{\frac{2}{\epsilon_r + 1}} \tag{1}$$

The effective dielectric constant of patch antenna ϵ_{reff} is expressed as,

$$\epsilon_{reff} = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2}\left(\frac{1}{\sqrt{1+12\frac{h}{W}}}\right) \qquad \text{for } \frac{W}{h} > 1 \tag{2}$$

The extension length (ΔL) is determined by

$$\Delta L = 0.412h\frac{(\epsilon_{reff}+0.3)(\frac{W}{h}+0.264)}{(\epsilon_{reff}-0.258)(\frac{W}{h}+0.813)} \tag{3}$$

The effective length of the patch antenna (L_{eff}) is expressed by

$$L_{eff} = \frac{c}{2f\sqrt{\epsilon_{reff}}} \tag{4}$$

The patch length is given by

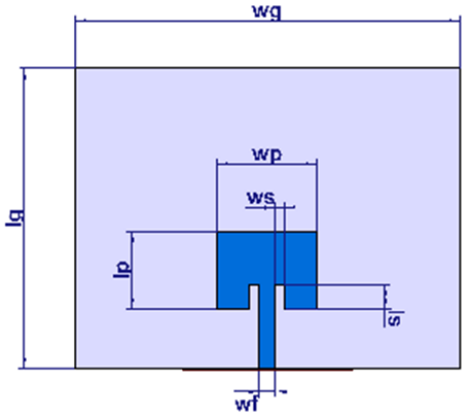
$$L\ (\text{length of the patch}) = L_{eff} - 2\Delta L \tag{5}$$

The final optimized dimensions of the proposed antenna are demonstrated in Table 1. CST software is used to determine the optimum parameters of the proposed patch antenna.

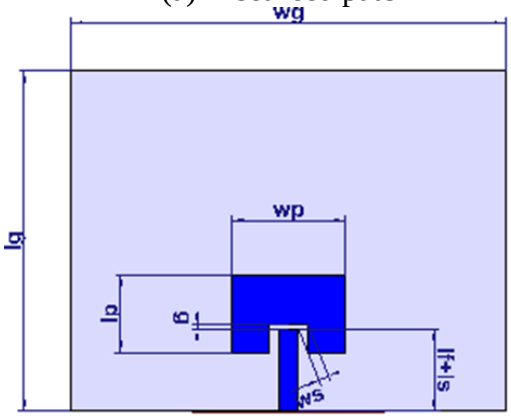
Table 1 antenna parameters

Symbol	Dimension (mm)
Patch Length (lp)	2.28 (in inset feed) and 2 (in coupled feed)
Patch Width (wp)	2.9
Substrate or ground Length (lg)	8.75
Substrate or ground Width (wg)	11.2
Dielectric constant of the substrate	4.3
Height of the substrate	0.699
Height of the conductor	0.035
Transmission line Width (wf)	0.5
Transmission line Length (lf)	1.731
Length of patch slot (ls)	0.715
Width of patch slot (ws)	0.25
Gap of coupled feed patch (g)	0.1

The rectangular microstrip antenna is excited by two types of feeding. Figure 1(a) shows the microstrip patch using an inset feed line. In this method, the radiating patch is connected directly to the feedline in the same plane. An inset feed point can be created by notching the patch (ls). Figure 1(b) depicts a microstrip patch antenna using gap coupled feed line. As seen in the figure, this type of feeding is similar to inset feed, except the radiating element here doesn't touch the feedline. This type of feeding is done indirectly through a very small gap. Both patches were placed on substrate material of FR-4 (4.3 dielectric constant, and 0.025 loss tangent) with dimensions of 11.2mm ×8.75mm × 0.699mm (width× length× height). This substrate is printed on the ground made of copper with dimensions of 11.2mm ×8.75mm × 0.035mm (width× length× height). The feed length of the patch is 1.7mm, and the feed width is 0.5mm for both types of feeding.



(a) Inset feed patch



(b) Coupled feed patch

Figure 1 Top view of the microstrip patch antenna

3. RESULTS OF THE SIMULATION

The results of the simulated patch antenna using the above-mentioned feeding methods are shown in this section. Figure 2 depicts the S_{11} parameter of the microstrip patch using inset-fed and coupled feeding techniques. The return loss of the inset-feed microstrip patch is -19 dB with a -10 dB frequency bandwidth of 2 GHz at 28 GHz. However, the coupled-feed patch antenna achieves a lower loss of -35 dB with a slightly higher frequency bandwidth of -2.3 GHz at 28 GHz.

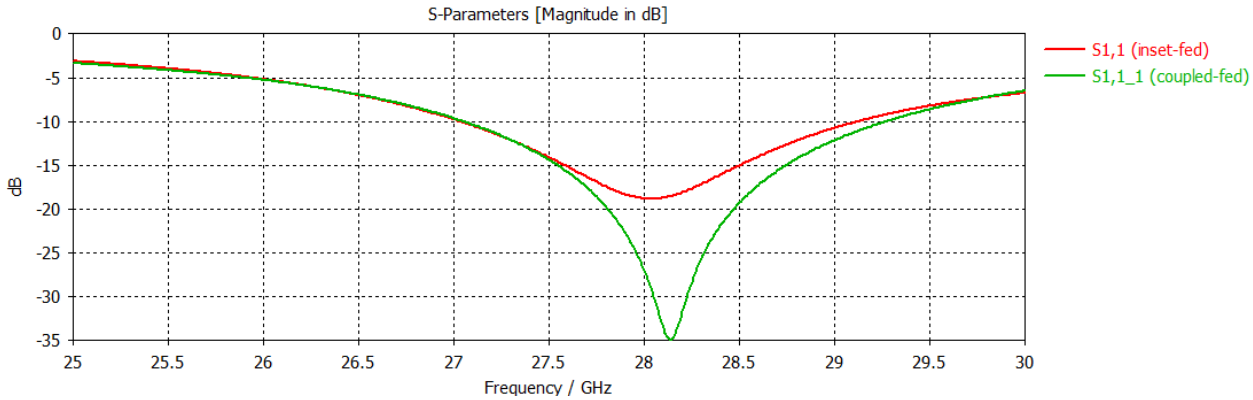
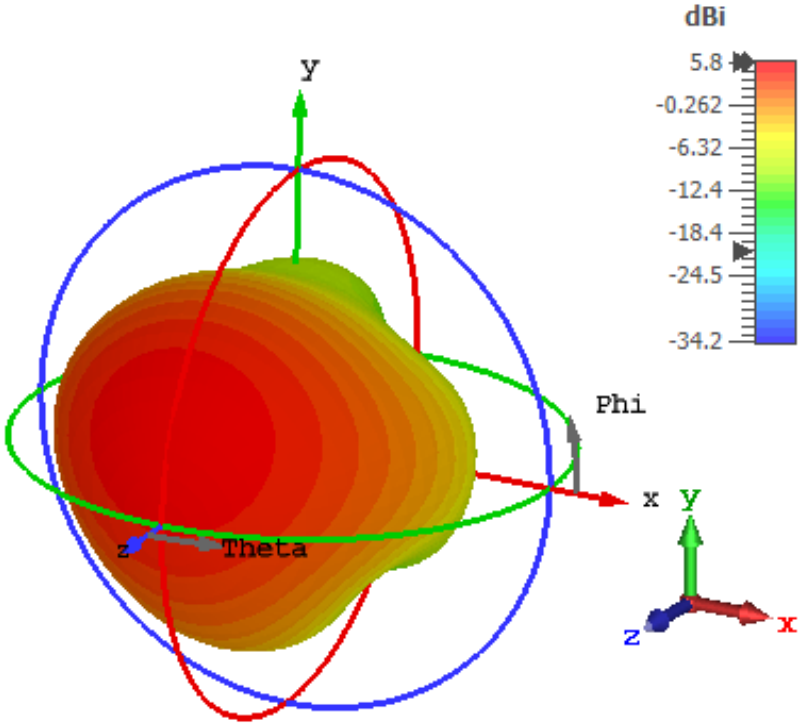
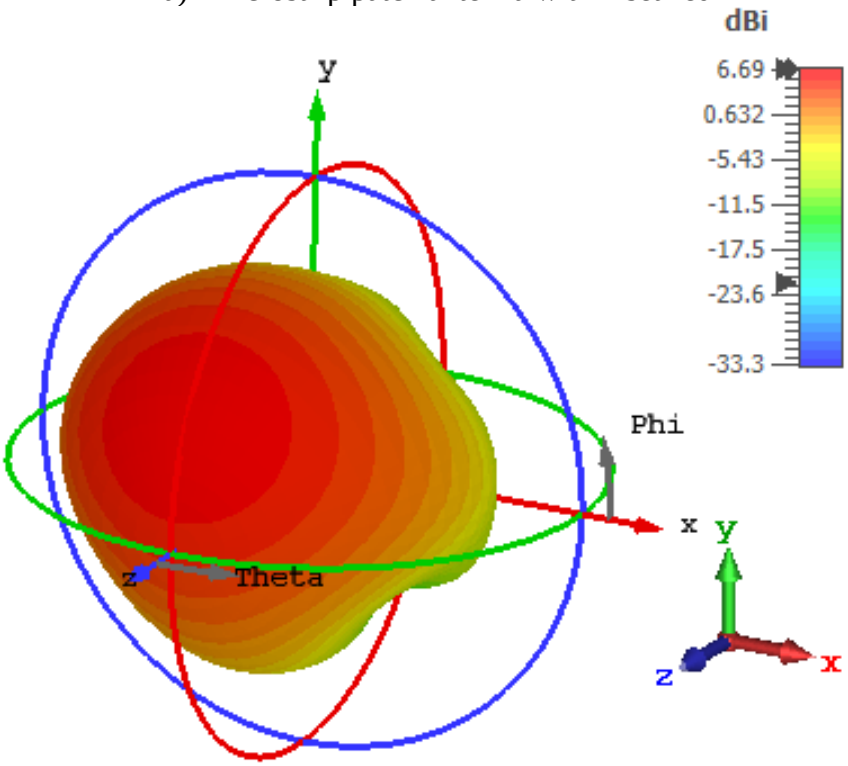


Figure 2 simulated reflection coefficient for two feeding methods

The far-field gain results for both feeding techniques are illustrated in the 3D plot shown in Figure 3. As seen from this figure, the coupled-fed patch antenna achieves a gain value of 6.7 dBi, while the inset-fed antenna achieves a gain of 5.8 dBi. The maximum gain response of the microstrip patch using both feeding methods is shown in Figure 4. The figure demonstrated that the gap-coupled fed antenna obtains better peak gain response when compared to the antenna with an inset-feed.



a) microstrip patch antenna with inset-fed



b) microstrip patch antenna with gap coupled-fed

Figure 3 3D view of far-field gain

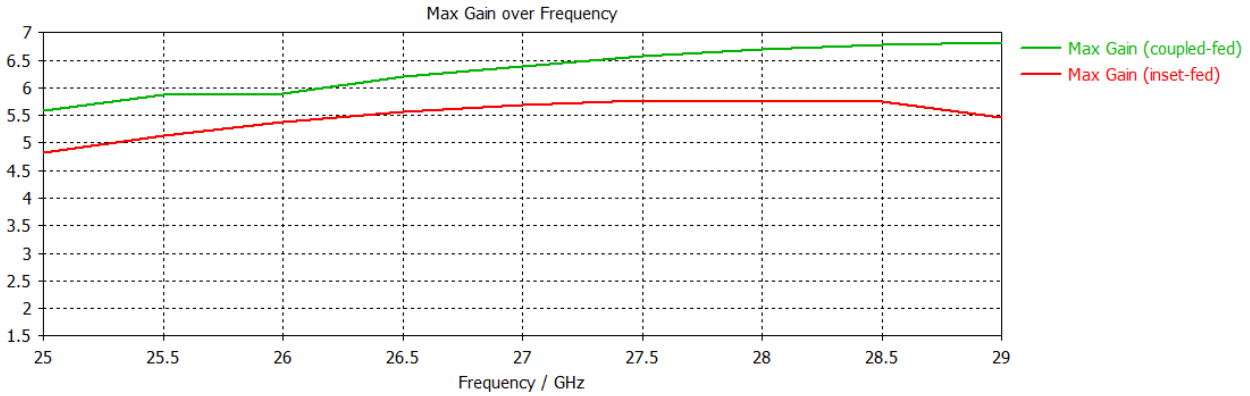


Figure 4 max gain over frequency of microstrip antenna

4. CONCLUSIONS

In this study, a microstrip patch resonating at 28 GHz has been reported using two feeding methods: the inset and the gap-coupled. The performance of the simulated antenna has been presented using the CST tool. The coupled feed gives better radiation performance in terms of return loss and gain compared to the inset feed method. The results show that the coupled feed antenna can attain a return loss and gain of (-35 dB and 6.7 dBi) at 28 GHz. The obtained results reveal that the proposed antenna with coupled-fed is more recommendable to be used in 5G applications.

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MSBEHAVIOR NODE IN WIRELESS MOBILE AD HOC NETWORKSS

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ABSTRACT
Wireless Mobile Ad hoc Network (MANET) has become one of the most important wireless communication mechanisms among all, unlike traditional network. MANET does not have a fixed infrastructure. Every single node in the MANET works as both receiver and transmitter. Each node directly communicates with others when they are both within their communication ranges. All nodes work as routers and take path in discovery and maintenance of routes to other nodes in the network. In this paper proposed a new routing algorithm named Enhanced Adaptive 3 Acknowledgement (EA3ACK) using EAACK specially designed for MANET. This hybrid cryptography a two key method namely MARS4 which is a combination of RSA and MAJE4 employed to reduce the routing overhead. The proposed EA3ACK algorithm provides efficient secured transmission compare to existing EAACK algorithm.
Keywords*:* EA3ACK, IDS, Security, MANET, Throughput.

1. INTRODUCTION

As shown in the fig 1 nodes of a MANET do not have a centralized administration mechanism. It is known for its routable network properties where each node act as a "router" to forward the traffic to other specified node in the network. MANET were wireless multi-hop networks without any fixed infrastructure and centralized administration, in contrast to today's wireless communications, which is based on fixed, pre-established infrastructure. All networking functions, such as determining the network topology, multiple accesses, and routing of data over the most appropriate paths, must be performed in a distributed way. These tasks are particularly challenging due to the limited communication bandwidth available in the wireless channel.

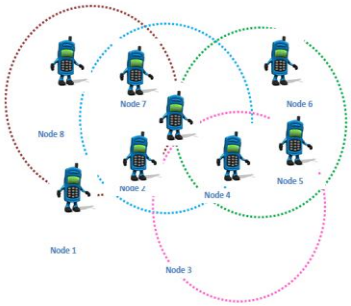

Figure 1 Mobile Ad hoc Networks

2. BACKGROUND

Routing Protocol: A routing protocol specifies how routers communicate with each other, disseminating information that enables them to select routes between any two nodes on a computer network. Routing algorithms determine the specific choice of route. Each router has a priori knowledge only of networks attached to it directly. A routing protocol shares this information first among immediate neighbors, and then throughout the network. The two main types of routing: Static routing and dynamic routing. Generally, there are two different stages in routing; they are route discovery and data forwarding. In route discovery, route to a destination will be discovered by broadcasting the query. Then, once the route has been established, data forwarding will be initiated and sent via the routes that have been determined. The power consumption, route relaying load, battery life, and reduction in the frequency of sending control messages, optimization of size of control headers and efficient route reconfiguration should be considered when developing a routing protocol. **Proactive:** approach every node generates routing information periodically to maintain and construct routing tables even if there is no data traffic to deliver. Information contained in routing tables, is updated when the topology changes. Thus, every node maintains routing information to every other node in the network. Proactive routing protocols may use either hop-by-hop or source routing strategies to forward data traffic. The performance of the network degrades due to the exchange of control traffic messages, but the packets experience less latency because the routes are always constructed and maintained for eventual data traffic. Proactive protocols work better in networks with low mobility. **Reactive:** routing protocols discovery and maintenance of routes are delayed until necessary. When a given node needs to send a packet to any other node in the network, the sender node initiates the process to construct a path to reach the destination. To discover a route, a node floods the route request messages through the network. When a node with a route to the destination (or the destination itself) is reached, a route replay message is sent back to the source node. Reactive protocols can be classified into two categories: source routing and hop-by-hop routing. **Hybrid** routing protocol is a combination of proactive and reactive routing protocol. Zone-based Hierarchical Link State (ZHLS) is a typical example. According to ZHLS routing protocol, the entire network is divided into several non-overlapping

zones. If the source and destination nodes are within the same zone, ZHLS works as a passive routing protocol. **Cryptography:** Cryptography technique has a long and fascinating history. Completed in 1963, the Kahn's book covers the most important history of cryptography technique. From 4,000 years ago by the Egyptians, to the two world wars in the twentieth century, the cryptography technique has been widely served as a tool to protect secrets. With the development of Internet, the security of communication has become more important than ever. Many researchers and scientists have contributed their countless time and efforts in this area since then. Among all of them, it is believed the most significant development was in 1976 when Diffie and Hellman published the paper "New Directions in Cryptography", in which they first introduced the concept of public-key cryptography. Although no practical implementation was provided along with the paper, the idea had since then attracted various attentions and interests. Two years later, in 1978, Rivest, Shamir and Adleman proposed the first practical public-key encryption and signature scheme, which we now referred to as RSA. Later after that, the 1980s has witnessed much more advancement in this area but none of them rendered RSA as insecure. EIGamal in 1985, found another class of powerful and practical public-key schemes. These are also based on the discrete logarithm problem.

3. PROPOSED SYSTEM

MARS4: Now MAJE4 and RSA can be combined to have MARS4 as a very efficient security solution. Assume that A is the sender of a message and B is the receiver. MARS4 is designed to work as follows.

a. A encrypts the original message (PT) with the help of MAJE4 and the symmetric key (K1) and forms the cipher text (CT).
b. Encrypt K1 (CT) to (K2) of B using RSA.
c. B now uses the RSA algorithm and its private key (K3) to decrypt K1.
d. Then B uses K1 and the MAJE4 algorithm to decrypt the CT for the original plain text (PT).

FLOW DIAGRAM

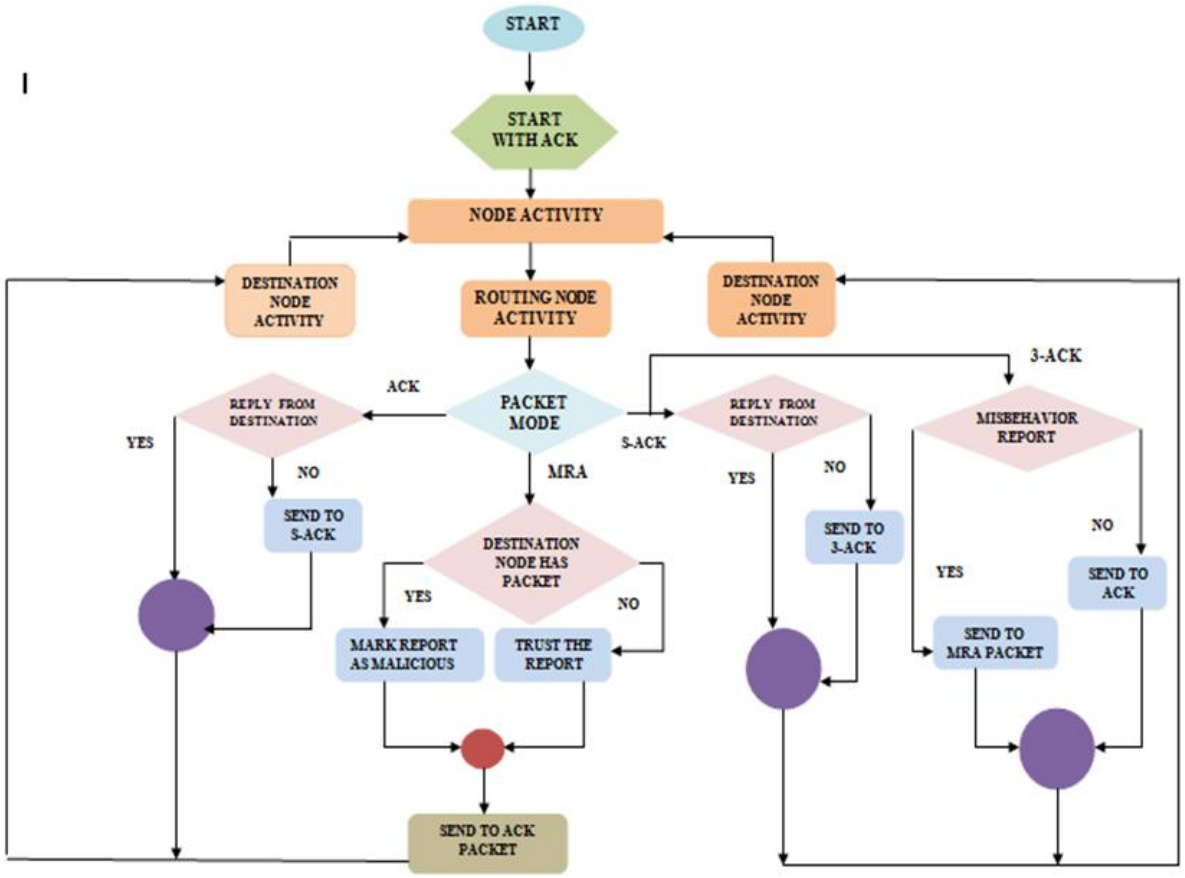

Figure 2 Flow diagram for EA3ACK

In this section, we describe our proposed EA3ACK scheme in detail. The approach described in this research paper is based on previous work (2), where the backbone of EA3ACK was proposed and evaluated through implementation. We extend it with the introduction of MARS4 Hybrid cryptography to prevent the attacker from forging acknowledgment packets. EA3ACK is consisted of four major parts, namely, ACK, secure ACK (S-ACK), 3-ACK and misbehaviour report authentication (MRA). In order to distinguish different packet types in different schemes In EA3ACK, we use 3 b of the different types of packets. Details are listed in Fig 2 presents a flowchart describing the EA3ACK scheme. Please note that, in our proposed scheme, we assume that the link between each node in the network is bidirectional. Furthermore, for each communication process, both the source node and the destination node are not malicious. Unless specified, all acknowledgment packets described in this research are required to two different keys (public and private) by its one key for sender and verified another key by its receiver.

4. RESULT AND DISSCUSSION

Simulation Configurations: In this section, we evaluate the performance of routing protocol of MANETs in an open environment. The simulations were carried out using network simulator (NS 2.34). We are simulating the mobile ad hoc routing protocols using this simulator by varying the number of nodes. The IEEE 802.11 distributed coordination function (DCF) is used as the medium access control protocol. The traffic sources are UDP. Initially nodes were placed at certain specific locations. The simulation parameters are specified in Table 1

Parameters	Values
Simulation area	1,000 m *
Number of nodes	60
Average speed of	0–25
Mobility model	Random
Number of packet	40
Transmission range	250 m
Constant bit rate	2
Packet size	512 bytes
Node beacon interval	0.5 (seconds)
MAC protocol	802.11 DCF
Initial energy/node	100 joules
Antenna model	Omni
Simulation time	500 sec

Table 1 Simulation parameters

In this section, malicious nodes drop all the packets that pass through it. Fig 3 and Table 2 shows the simulation results that are based on PDR.

Packet Delivery Ratio					
Routing / Malicious Node	**0%**	**10%**	**20%**	**30%**	**40%**
DSR	**1**	**0.82**	**0.73**	**0.68**	**0.66**
WATCHDOG	**1**	**0.83**	**0.77**	**0.70**	**0.67**
AACK	**1**	**0.96**	**0.96**	**0.93**	**0.92**
TWOACK	**1**	**0.97**	**0.96**	**0.92**	**0.92**
THREEACK	**1**	**0.96.5**	**0.96**	**0.91**	**0.92**
EAACK(RSA)	**1**	**0.96**	**0.97**	**0.92**	**0.92**
EEACK(DSA)	**1**	**0.96**	**0.97**	**0.93**	**0.91**
EA3ACK	**1**	**0.97**	**0.97**	**0.96**	**0.95**
Routing Overhead					
Routing / Malicious Node	**0%**	**10%**	**20%**	**30%**	**40%**
DSR	**0.02**	**0.023**	**0.023**	**0.022**	**0.02**
WATCHDOG	**0.02**	**0.025**	**0.025**	**0.023**	**0.023**
AACK	**0.03**	**0.23**	**0.32**	**0.33**	**0.39**
TWOACK	**0.18**	**0.4**	**0.43**	**0.42**	**0.51**
THREEACK	**0.19**	**0.43**	**0.45**	**0.42**	**0.50**
EAACK(RSA)	**0.16**	**0.3**	**0.37**	**0.47**	**0.61**
EEACK(DSA)	**0.15**	**0.28**	**0.35**	**0.44**	**0.58**
EA3ACK	**0.14**	**0.26.5**	**0.32**	**0.40**	**0.55**
Throughput					
Routing / Malicious Node	**0%**	**10%**	**20%**	**30%**	**40%**
EAACK(RSA)	**0**	**0.25**	**0.38**	**0.50**	**0.54**
EEACK(DSA)	**0**	**0.27**	**0.40**	**0.53**	**0.57**
EA3ACK	**0**	**0.37**	**0.50**	**0.63**	**0.58**
Energy					
Routing / Malicious Node	**0%**	**10%**	**20%**	**30%**	**40%**
EEACK	**1**	**0.95**	**0.89**	**0.80**	**0.76**
EA3ACK	**1**	**0.92**	**0.84**	**0.76**	**0.72**

Table 2 Performance Comparison

In Fig 3 and Table 2 we observe that all acknowledgment-based IDSs our proposed scheme EA3ACK surpassed EAACK performance by above 95% when there are 30% and 40% of malicious nodes in the network. From the results, we conclude that acknowledgment-based schemes, EA3ACK, are able to detect misbehaviors with the presence of receiver collision, limited transmission power and partial dropping.

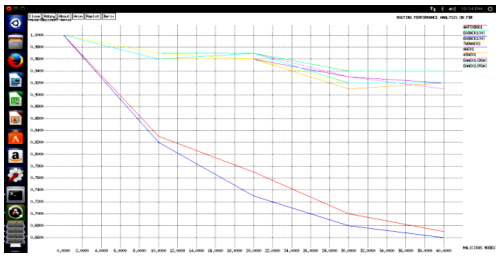

Figure 3 PDR vs. Malicious Nodes

Simulation results are shows that fig 4 and table 2. We observe that DSR scheme achieve the best performance, as they do not require acknowledgment scheme to detect misbehaviors. For the rest of the IDSs, EA3ACK has the lowest overhead when there are 10% to 30%.

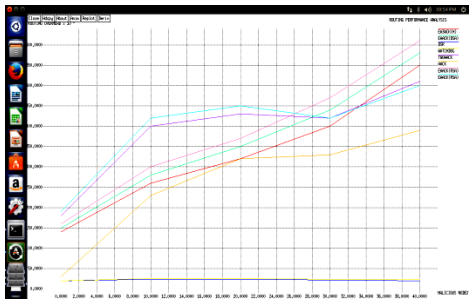

Figure 4 Routing Performance vs. Malicious Nodes

Simulation results are shows that fig 5 and table 2 shows that comparison of the EAACK with corresponding RSA and DSA algorithm since on along with EA3ACK where it shows the throughput is increase with increase in the number of malicious nodes on while 30% and 40%.

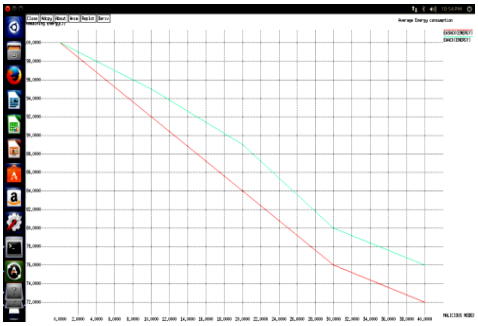

Figure 5 Average Energy Consumption vs. Malicious Nodes

Simulation results are shows that fig 6 and table 2 shows that our proposed EA3ACK deceasing the remaining energy with increasing malicious nodes compare to the existing algorithm.

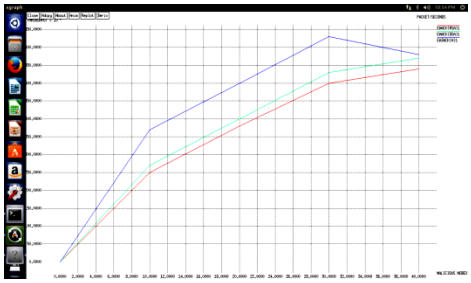

Figure 6 Packer per/sec vs. Malicious Nodes

Simulation results are shows that the all above figure and Table shows that the comparison of the EAACK with corresponding RSA and DSA algorithm since on along with EA3ACK with hybrid cryptography where it shows the throughput is increase with increase in the number of malicious nodes on while.

5. CONCLUSION

In the recent research year there has been a lot of interest within the field of cryptography in MANET. Because during the transmission drop (or) attack the packet without the acknowledgement. So acknowledge based transmission is very safe and high security. The motivation for our work is to develop an Intrusion Detection System (IDS) scheme able to detect misbehaving node in case of collision, limited transmission power and false misbehavior report. We demonstrated the performance of our proposed scheme named EA3ACK with hybrid cryptography using EAACK through an evaluation in the network simulator environment. This EA3ACK provide better performance compare to existing EAACK routing protocol and also improved packet delivery ration, improved throughput, and reduced routing overhead compare to existing EAACK routing protocol. Finally EA3ACK shows that the result of proposed scheme is effective in detecting misbehaving nodes in MANET.

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FABRİKA OTOMASYONUNDA STOK YÖNETİMİ: ABC ANALİZİ İLE KRİTİK MALZEME SINIFLANDIRMASINA İLİŞKİN BİR UYGULAMA

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ÖZET

Fabrika otomasyonu, üretim süreçlerini daha verimli hale getirmek için günümüz teknolojinin kullanıldığı önemli bir yöntemdir. Bu sektörde envanter yönetimi, üretim süreçlerinin sürekliliğini sağlamak ve maliyetleri minimize edilmesinde kritik rol oynamaktadır. Envanter yönetimi, bir fabrikanın ham madde, yarı mamul ve nihai ürünlerinin etkin bir şekilde kontrol edilmesi ve izlenmesi sürecidir. Otomasyon sistemleri, bu süreçlerin daha hızlı ve doğru bir şekilde yapılmasına olanak tanımaktadır. Modern envanter yönetim sistemleri, gerçek zamanlı veri toplama, analiz ve izleme teknolojileriyle entegre çalışarak envanterdeki tüm ürünleri anlık olarak takip edebilmesine olanak sağlamaktadır. Bu sistemler, stok seviyelerinin izlenmesi, tedarik zinciri yönetimi ve üretim planlaması gibi işlemleri kolaylaştırır. Fabrikalarda otomasyon kullanımı, manuel hataları azaltmakta ve iş gücü maliyetlerini düşürmektedir. Ayrıca envanter yönetimi yazılımları, üretim süreçlerini optimize etmek, malzeme israfını engelleyerek atık miktarını azaltmak ve stok fazlası ya da eksikliği gibi problemleri ortadan kaldırmak için tasarlanmıştır. Ayrıca, otomasyon sayesinde üretim hattındaki her aşama için doğru envanter bilgisi elde edilmekte, bu da karar alma süreçlerini iyileştirip zaman kayıplarını engellemektedir. ABC analizi, malzeme yönetiminde en sık kullanılan yöntemlerden biri olup, malzemelerin önem derecelerine göre sınıflandırılmasını sağlamaktadır. Bu analiz, özellikle üretim ve envanter yönetiminde kaynakların verimli bir şekilde kullanılmasında önemli bir rol oynamaktadır. ABC analizi, malzemeleri A grubu (yüksek değerli ve düşük miktarda kullanılan malzemeler), B grubu (orta değerde olan ve orta miktarda kullanılan malzemeler) ve C grubu (düşük değerli ve yüksek miktarda kullanılan malzemeler) olmak üzere üç ana kategoriye ayrılmaktadır.

Bu çalışmada, bir X firmasında ABC analizi ile malzeme sınıflandırmasının, envanterdeki fazla stokları azaltma, tedarik zinciri süreçlerini optimize etme ve maliyetleri düşürme gibi avantajları olup olmadığı araştırılmıştır. Üretim endüstrisinde kullanılmak üzere tasarlanan fikstür, envanterlerin ABC analizi açısından grup A olarak sınıflandırılabilen 14 bileşenden oluşmakta ve üretimin en önemli malzemesidir. 2023-2024 dönemi için ortalama aylık satın alımlar ve malzeme tüketimi dikkate alınmıştır. Elde tutulan stokların, tüketimin belirtilen miktarı aşmayacağı ve tüketimin belirtilen miktarı aşacağı ve açığa yol açacağı olasılık değerlerine karşılık gelen olasılık değerleri atanmıştır. Siparişlerin standart sapmaları ve yükseltilmiş standart sapmaları hesaplanarak tahminler yapılmıştır.

Anahtar Kelimeler: Fabrika otomasyonu, envanter yönetimi, ABC analizi

INVENTORY MANAGEMENT IN FACTORY AUTOMATION: AN APPLICATION ON CRITICAL MATERIAL CLASSIFICATION WITH ABC ANALYSIS

ABSTRACT

Factory automation is an important method that utilizes modern technology to make production processes more efficient. In this sector, inventory management plays a critical role in ensuring the continuity of production processes and minimizing costs. Inventory management is the process of effectively controlling and tracking a factory's raw materials, semi-finished products, and finished goods. Automation systems enable these processes to be carried out more quickly and accurately. Modern inventory management systems integrate with real-time data collection, analysis, and monitoring technologies, allowing for the instant tracking of all products in inventory. These systems facilitate tasks such as monitoring stock levels, supply chain management, and production planning. The use of automation in factories reduces manual errors and lowers labor costs. Additionally, inventory management software is designed to optimize production processes, prevent material waste, reduce waste amounts, and eliminate problems like stock surpluses or shortages. Furthermore, through automation, accurate inventory data for each stage of the production line is obtained, which improves decision-making processes and prevents time losses. ABC analysis is one of the most commonly used methods in material management, classifying materials based on their importance. This analysis plays a significant role in efficiently utilizing resources, especially in production and inventory management. ABC analysis divides materials into three main categories: Group A (high-value, low-usage materials), Group B (medium-value, medium-usage materials), and Group C (low-value, high-usage materials).

In this study, the advantages of material classification using ABC analysis, such as reducing excess stock in inventory, optimizing supply chain processes, and reducing costs, have been examined at a company X. The fixture designed for use in the manufacturing industry consists of 14 components that can be classified as Group A based on ABC analysis and are the most critical materials in production. Average monthly purchases and material consumption for the 2023-2024 period were considered. The probabilities corresponding to the possibility that the held stocks will either not exceed the specified consumption amount or exceed it, causing a shortage, were assigned. Standard deviations and elevated standard deviations of orders were calculated to make forecasts.

Keywords: Factory automation, inventory management, ABC analysis

1. Introduction

Factory automation is a technological solution that enables end-users to configure a software robot to use existing applications to perform operations, process data, and communicate with other systems. Simply put, factory automation means making production automatic by enabling machines and software to work together. The primary goal here is to increase efficiency, reduce production costs, minimize human error, standardize quality, and speed up production. Software robot systems can access multiple systems, applications, and documents simultaneously, if needed. Robots can operate on the user interface just like humans, which eliminates the need to change applications (such as accounting, inventory, ERP software) or the core IT infrastructure. To ensure data integrity and meet audit requirements, every operation is monitored, logged daily, and analyzed. Typical office tasks that software robots can undertake include opening, reading, and forwarding emails, searching for, updating, verifying, and processing data across multiple applications, and making necessary decisions (Sezen, 2004).

Factory automation is an alternative to traditional automation. Traditional automation requires programmers and software vendors to develop custom software and integrate it into existing systems. While the potential benefits of traditional automation are higher, it is more difficult to implement and requires significant effort, time, and cost. Factory automation can be used as a technology solution offering cross-functional and multi-system operations without unwanted interventions to the existing infrastructure (Lacity & Willcocks, 2016). Factory automation offers an opportunity to improve the performance of processes in companies where traditional automation is impossible or too complex and therefore too expensive to deploy. The solution provides direct feedback on workflow and progress. It has proven useful for processes that include steps which cannot be automated, such as those requiring human approval, decision-making, or the handling of urgent exceptions (Baykoç et al., 2002).

The integration of artificial intelligence with factory automation offers intelligent process automation (Truong, 2021). The implementation of factory automation using an unattended approach (especially when integrated with AI, cloud, or blockchain technologies) is more expensive, complex, and time-consuming compared to the attended version. However, cost and time are still lower than those required for full traditional automation.

Until recently, automation software solutions required a human to operate them; however, factory automation enables specific tasks to be fully undertaken by bots. Therefore, the main advantage of factory automation is not the technology itself, but rather the liberation of human resources, allowing people to focus on activities that require reasoning, decision-making, or interaction with employees or customers. The key benefits of factory automation are listed below:

- Cost reduction – particularly when deployed at scale, it can significantly reduce the costs of accounting and finance tasks (Le Clair, 2017). Typically, a single robot can replace two to five full-time employees.
- Increased process speed – performs routine tasks more quickly (Lacity & Willcocks, 2016).
- Improved process control and performance visibility – since every operation is fully tracked and logged, it allows effective task monitoring (Lacity & Willcocks, 2016).
- Higher quality data (accuracy, consistency, compliance) – strictly follows predefined rules and protocols (Lacity & Willcocks, 2016).
- Continuous operation (24/7) – can be configured to serve a process continuously or to sequentially perform multiple tasks across various processes.
- Enhanced process flexibility for easier scalability – can adapt to changing workloads (Lacity & Willcocks, 2016).

- Relative ease of implementation – does not require programming skills (Fersht & Slaby, 2012).
- Geographical and cultural independence – can serve multiple work locations in a single day, eliminating issues caused by time zone differences or cultural and language barriers.
- Positive impact on employees – reduces repetitive work and increases job satisfaction (Lacity & Willcocks, 2016).

Among the most compelling reasons for companies to consider factory automation are its relative ease of implementation and lower costs and skill requirements compared to traditional, fully integrated automation. According to a survey conducted by Capgemini, factory automation emerged as the most popular technology for automating back-office and mid-office functions. Prior to automation, the payback period ranged from 7 to 12 months, and the return on investment (ROI) varied between 13% and 18%. Of the companies analyzed, 31% had implemented automation in the finance and accounting domain, achieving an average ROI of 12% and a payback period of 11 months. Finance and accounting automation also provided the highest cost savings (an average of 13%) compared to other back-office departments.

2. Factory Automation, Inventory Management, and ABC Analysis

2.1. Factory Automation

Robotic Process Automation (RPA) often carries a futuristic connotation. The concept frequently leads people to imagine physical robots moving around office spaces, performing tasks just like humans. Moreover, the tasks in question are typically repetitive and less preferable to perform manually. Such tasks are often labeled as "swivel chair" activities—referring to the transfer of inputs from one system to another with little need for interpretation. Stripped of its mystique, this is the only space where factory automation interacts with systems just like a human. However, given a proper process and well-defined logic, a robot is expected to outperform humans in terms of quality, speed, and cost (Willcocks et al., 2015).

Factory automation software comes equipped with a robust analytics suite that tracks the performance of the robotic workforce. Most enterprise-level automation systems monitor and manage automated functions via a central console, which is accessible from anywhere. This console provides key metrics related to robots, servers, workflows, and more. Detailed operational analysis not only allows users to monitor processes and identify issues but also supports planning for future workloads. This solution typically requires no integration, as it is ready to deploy out of the box with all components built-in.

When an organization works with automation, it is likely that many users will require access to the automation platform. At this point, strong user access management is critical. That's why factory automation tools include role-based security, enabling action-specific permissions. Additionally, many RPA tools offer encryption features to protect specific types of data and to defend against network interruptions, while also allowing for customization. All automated data, logs, and instructions accessed by bots are encrypted to prevent malicious interference and ensure the legitimacy of historical audit trails.

The factory automation system is designed for client deployment across virtual machines, terminal services, and cloud environments. Among deployment options, cloud deployment is the most attractive due to its scalability and flexibility. Additionally, the system is powerful enough to automatically deploy robots in groups of hundreds. This feature includes an agentless setup that prevents client configuration and bot deployment conflicts, proactively eliminating server synchronization issues and runtime update delays.

The system also supports deployments with rule-based exception handling. This feature proactively responds to errors. For example, if a robot reports an exception, the server reassigns the same task to another bot and removes the first bot from production. If the retry is successful, the server continues with reassignments and raises a Level 2 alert to report the exception and its resolution. If the retry fails, it stops the second bot and raises a Level 1 alert to report both the failure and the exception.

Modern factory automation tools are code-free and capable of automating any type of application in departments across the organization where administrative or clerical tasks are performed.

Artificial intelligence and cognitive intelligence are common features in today's factory automation solutions. These systems may include machine learning, computer vision, and cognitive automation to help bots improve their decision-making over time. As a result, many of their functions can be fully automated without the need for additional extensions.

A process behaves like a human user who thinks and types extremely fast. Today, every manual user typically works from their own desktop Windows machine. For a process to replace this user, it also requires access to its own Windows desktop environment. However, when using Blue Prism, this does not require numerous dedicated physical machines. Instead, each process instance usually runs on its own Windows virtual machine (VM).

The software robot used to automate this business process is a Blue Prism process, and the three business objects it utilizes also run within the same VM. This robot appears just like an ordinary user in each of the applications it interacts with. In enterprise business applications, multiple concurrent users are commonly required. Achieving this with Blue Prism means deploying multiple VMs, each running a robot instance.

As illustrated in the architecture, a single physical server typically runs a portion of these VMs. The Blue Prism application server acts as a central control point for all these robots. At the same time, all robots share the Blue Prism database, which serves as a common repository for the environment. This database stores each robot's code, work queues they interact with, audit logs, and more.

It is typically implemented using SQL Server with Always-On Availability Groups, providing a redundant and reliable repository for the enterprise factory automation environment.

Work queues play a crucial role in Blue Prism environments. Items to be processed—such as customer orders—can be placed in a queue and then handled simultaneously by multiple robots, enabling parallel processing and high efficiency.

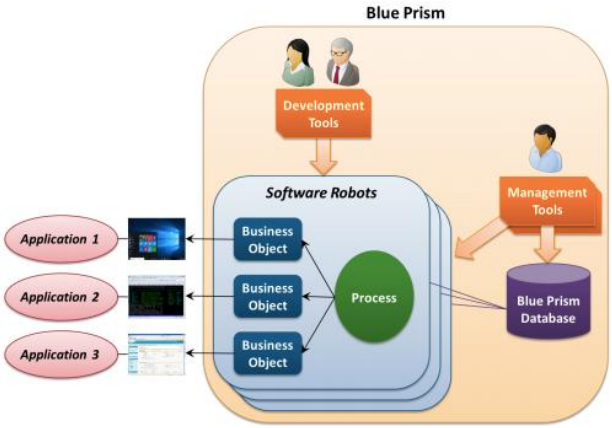

Figure 1. Blue Prism working principles

2.2. Blue Prism Application

Any application designed for enterprise deployment must address security directly, and Blue Prism is no exception. One of the key security foundations in the product is role-based access control (RBAC). Once the Blue Prism administrator defines which roles a user can perform, the system ensures that the user is only allowed to execute actions that are authorized by those roles.
Blue Prism also tracks significant changes within its environment. Using the System tab, the administrator can review logs of actions such as a user logging into Blue Prism, starting or deleting a robot, changing a user's password, and more.

Another important consideration for Factory Automation technology is securely managing usernames and passwords used to log into applications. To achieve this, Blue Prism supports Active Directory, which is the identity management method used by most Blue Prism customers. Additionally, if required, the product provides a database of encrypted credentials controlled by the Blue Prism administrator, which can be utilized for secure login management.
Blue Prism also offers the ability to create and use control panels. Each control panel consists of a collection of tiles, and the administrator can configure exactly which tiles should appear in the control panel.

2.3. Use of Factory Automation Document in the World of Automation

The documents used in factory automation development vary from tool to tool and organization to organization, but they are generally used in the following 5 processes in automation projects:

- Initial Process Analysis (IPA)
- Process Definition Document (PDD)
- Solution Design Document (SDD)
- Functional Requirements Questionnaire (FRQ)
- Development Specification Document (DSD)

These are typically created by a Business Analyst or Developer and reviewed or approved by the customer/sponsor. They provide enough information for you to decide whether you want to proceed with automating the process.
They generally include questions like:

- How many FTEs (Full-Time Equivalents) are currently required to perform the task manually?
- What is the average time to complete the task?
- Will this task be scheduled or executed on-demand?
- What is the expected maximum and minimum volume?
- Are there periods of time when a higher workload is expected? If so, what are they?
- Is there any SLA (Service Level Agreement) that this solution needs to comply with?

The Process Definition Document (PDD) captures the flow of a business process to be automated. The flowchart in the document provides a high-level reflection of the business process to be automated, the target systems used within the process, and all the assumptions considered. If existing process documentation will be used instead of a new PDD, the following steps should be taken:

- Review existing process documentation to ensure it is up to date and fully covers the current manual process.
- Determine whether the existing process documentation provides the same level of detail required for automation.
- Ensure that the manual process is accepted by the business as an accurate description.

The customer is expected to review the SDD and approve the solution to continue development. The SDD outlines the key components of the project (which may include one or more projects and together cover the scope of factory automation development) while considering all business constraints (such as timing, peaks, and future volume increases). The information here is primarily directed at the developers who will first implement the solution, and then to support developers in case of change requests.

The Development Specification Document (DSD) is created for each business process automated using Factory Automation technology. The DSD must be reviewed and updated for each change requested and applied to the automation process.

2.4. Inventory Management and ABC Analysis

2.4.1. Inventory Management

The goal of inventory management for businesses is not only to meet the needs of specific customers and groups but also to minimize the total cost under defined conditions. Therefore, businesses must reasonably formulate various inventory management processes to ensure the security and stability of corporate assets. From the current stage of corporate development, the most efficient and ideal inventory management method is undoubtedly the timely management of inventory. Additionally, with the widespread application of Internet of Things (IoT) technology in corporate inventory management, this area will become more scientific and efficient.

Inventory is also known as the goods and materials that a business stores and uses to achieve its production goals. Inventory management is primarily a discipline related to determining the arrangement of stored goods (Viale, 1996).

Stock management, especially within an organization, includes various capacities; these involve meeting customer demands and distinguishing them from uncertainties in these demands, separating different parts of the creation process, benefiting from quantity discounts, and providing support against inflation and value changes (Heizer and Render, 2014). It is a costly resource within the organization; thus, proper monitoring is essential for the organization's survival, building efficiency levels, eliminating unnecessary practices, reducing material waste, and ensuring low production costs. Inventory management is critical because organizations need to ensure the good management of assets and stock and significantly improve demand forecasting to prevent unplanned purchases.

To successfully implement zero-inventory management and achieve the expected impact from timely inventory management, two factors must be fully considered and properly addressed. First, how can stock levels be reduced as much as possible, and how can the ideal zero-stock condition be achieved? If a business cannot effectively reduce its stock levels, it cannot meet the preconditions and practical foundation for timely management. Second, when stock levels are low or even zero, how can the continuity of corporate production be ensured to avoid unnecessary resource consumption and avoid the assumed costs? On the one hand, if sufficient and uninterrupted supplies of raw materials, ongoing work, and auxiliary materials cannot be guaranteed during the business's continuous production process, the production process will inevitably be interrupted due to material shortages, resulting in halted production, idle corporate

resources, and numerous unnecessary expenses. On the other hand, if the qualified final product cannot be delivered within the time frame specified in the sales contract, the business will risk breaching the contract and fall into the disadvantageous situation of violating the sales agreement. This situation may lead to significant financial compensations and legal consequences, directly impacting the business's reputation and reliability. Therefore, the benefits of implementing the system on time outweigh the losses (Firuzan and Ayvaz, 2004).

Reducing inventory in the timely inventory management mode does not fundamentally solve the issue. Meeting customer needs, ensuring quality and quantity, and timely delivery are essential to a smooth and complete contract implementation. However, between the signing of the sales contract and the delivery of the product, several issues must be prepared by the production business, including the creation of the product production plan, material quotas, labor quotas, and material procurement: when the raw materials will be delivered to the business, when the product will be produced, and how it will be distributed after production. This requires businesses to comprehensively and reasonably plan the production process when signing sales contracts with customers, ensuring strict control at every production stage and preventing errors and defects. Of course, it can also be prevented and controlled by the business's alternative production lines and products. In any case, timely delivery must be ensured, neither too early nor too late. Early delivery will diminish the importance of the timely system. When the buyer demands delivery on the specified date in the contract, early delivery will inevitably lead to product accumulation, resulting in the business's inventory. Late delivery, on the other hand, will result in breach of contract and responsibility for anticipated obligations. Therefore, implementing timely management requires business managers to always maintain high concentration and carry out accurate data calculation procedures to respond sensitively to changes in the production environment and achieve the ideal situation without any discrepancies. In short, the only objective is to ensure quality, quantity, and on-time delivery. Specific measures to address this issue include expanding the production line scale, reducing the preparation time for raw materials and equipment in the early stages of production, ensuring the control of material circulation procedures, and more.

The key point of the timely inventory management method is that products are delivered to the buyer’s location on the day agreed upon in the sales contract. The aforementioned product production process is just one link in the timely inventory management chain. Another link in timely inventory management involves the product distribution process, meaning that after the product is completed, inventory must be transferred directly to the buyer's business.

The widespread application of Internet of Things (IoT) technology in modern finance provides technical support and scientific guarantees for the concept of timely inventory management. The integration of modern scientific and advanced information technology with efficient and reasonable inventory management methods increasingly highlights the advantages of corporate inventory management over traditional inventory management methods. The application of IoT technology to assist in inventory management not only saves human, material, and financial resources but also provides real-time monitoring and risk prevention for the inventory circulation process.

Appropriate stock levels are linked to the production schedule as a managerial response to market demand. Excess stock within an organization leads to increased costs, while too little stock results in sales losses, ultimately decreasing the organization's efficiency. One of the goals of inventory management is for an organization to "strike a balance between inventory investment and customer service," making it crucial. Inventory management is used to optimize inventory movement within organizations, share information between buyers and sellers, apply lean

production strategies, integrate supply chain management concepts, and implement a Just-In-Time (JIT) inventory system.

2.4.2. ABC Analysis

ABC analysis is an inventory management technique that determines the value of inventory items based on their importance to the business. ABC analysis ranks items according to demand, cost, and risk data, and inventory managers categorize these items based on these criteria. This helps business leaders understand which products or services are most critical to the financial success of their organizations. The most important stock-keeping units (SKUs), based on sales volume or profitability, are categorized as "Class A" items, followed by Class B items, and the least important as Class C items. Some companies may choose to use a classification system that divides products into more than these three groups (for example, A-F) (Prokopenko and North, 1997).

ABC analysis in cost accounting, or activity-based costing, is loosely related to but different from the inventory management ABC analysis. Accountants use activity-based costing in manufacturing to allocate indirect or overhead costs, such as utilities or salaries, to products and services.

With the increase in the use of Enterprise Resource Planning (ERP) systems, the use of the 80-20 rule has decreased. This is because, with the use of computers, concerns about where to prioritize resources may not be as significant as they once were. ABC analysis and the ERP system do not replace each other. Just because an ERP system is used for logistics does not mean that ABC analysis should be discontinued (Mattsson, 2003).

Component categorization can be effectively carried out with today's ERP systems. Generally, component categorization does not require manual effort and is easy to implement. Although categorization is cost-effective, it should not be applied too frequently. On the contrary, it is preferable for components to remain in the same ABC group over an extended period. If changes are made frequently in ABC categorization, there is a risk of confusion among employees, leading to uncertainty about which component belongs to which group.

Other ways to use ABC analysis include (Çevik, 2012):

- Minimizing setup costs in production by reducing the capital tied up in current inventory. The volume value should be the criterion in this categorization.
- Adjusting safety stock levels due to uncertain delivery times. The value of components and the average order quantity are the criteria.
- Reducing products in jobs. The criterion here is delivery times.
- Achieving automatic control of errors arising from a progress using control limits. In this case, ABC analysis uses the component value.
- Determining where components should be placed to make the picking order effective. The pull rate is the criterion for ABC analysis.

3. Materails and Methods

The proposed inventory management system designed for the manufacturing industry has been tested at a subcontracting company. The company specializes in designing and manufacturing a wide range of specialized tools, single-purpose machines, and technological components for the rationalization and automation of production processes on production lines. The welding fixture, which is a part of the source device in an automated line, is the subject of optimizing the inventory management system. The fixture designed for use in the manufacturing industry consists of 14

components, which can be classified as Category A according to the ABC analysis of inventory, meaning that it is made up of materials that constitute a significant portion of the fixture.
To determine the relationship between material purchases and inventory levels or to find out if the actual inventories correspond to material consumption, an overview of the inventories of input materials for the tracked product has been created. This overview includes average monthly purchases and material consumption for the period from January 1, 2024, to January 1, 2025.

Table 1. Inventory of the Materials

Sequence	Material	Inventory	Sequence	Material	Inventory
1	M1	48	8	M8	48
2	M2	120	9	M9	224
3	M3	120	10	M10	40
4	M4	80	11	M11	560
5	M5	60	12	M12	200
6	M6	100	13	M13	144
7	M7	72	14	M14	128

The general overview of the inventories of input materials validates the difference between actual consumption and the average monthly purchased quantities of materials. The result of this difference is unnecessary capital being tied up in inventories at a high rate. Observing this discrepancy has presented an opportunity to reduce inventory levels.

Table 2. Material Consumption

Material / Month	1	2	3	4	5	6	7	8	9	10	11	12	Total Consumption (unit)	Average Monthly Consumption (pcs)	Stan Devi
M1	3	3	6	6	3	6	3	3	6	6	3	3	51	4,25	1,54
M2	3	3	6	6	3	6	3	3	6	6	3	3	51	4,25	1,54
M3	3	3	6	6	3	6	3	3	6	6	3	3	51	4,25	1,54
M4	3	3	6	6	3	6	3	3	6	6	3	3	51	4,25	1,54
M5	3	3	6	6	3	6	3	3	6	6	3	3	51	4,25	1,54
M6	6	6	12	12	6	12	6	6	12	12	6	6	102	8,50	3,09
M7	2	2	4	4	2	4	2	2	4	4	2	2	34	2,83	1,03
M8	2	2	4	4	2	4	2	2	4	4	2	2	34	2,83	1,03
M9	10	10	20	20	10	20	10	10	20	20	10	10	170	14,17	5,14
M10	3	3	6	6	3	6	3	6	6	6	3	3	54	4,50	1,56
M11	15	15	45	45	15	45	15	15	45	45	15	15	330	27,50	15,4
M12	20	20	40	40	20	40	20	20	20	40	20	14	314	26,17	10,3
M13	6	6	12	12	6	12	6	6	12	12	6	6	102	8,50	3,09
M14	6	6	12	12	6	12	6	6	12	12	6	6	102	8,50	3,09

The likelihood of consumption values being different is very low. The probability of given values occurring decreases as they move away from the average. This fact is only worth considering when the expected monthly consumption is lower than what is required for the material. In the opposite case, all customers can be satisfied. Based on these assumptions, the stocks held are assigned probability values for the likelihood that consumption will not exceed the specified amount or will exceed the specified amount, potentially leading to a shortage.

Table 3. Material Consumption Growth

Material	Total Consumption	Expected Consumption Growth (%)	Expected Total Consumption	Expected Average Monthly	Raised Standard Deviation
M1	51	20	61	5,10	1,854
M2	51	20	61	5,10	1,854
M3	51	20	61	5,10	1,854
M4	51	20	61	5,10	1,854
M5	51	20	61	5,10	1,854
M6	102	20	122	10,20	3,707
M7	34	20	41	3,40	1,236
M8	34	20	41	3,40	1,236
M9	170	20	204	17,00	6,179
M10	54	20	65	5,40	1,880
M11	330	20	396	33,00	18,537
M12	314	20	377	31,40	12,427
M13	102	20	122	10,20	3,707
M14	102	20	122	10,20	3,707

If a comparison is made between the quantities ordered in the past and the recommended quantities, it can be concluded that the ordered quantity has been reduced, thereby freeing up capital funds for other purposes. In order to calculate the cost savings associated with capital tied up in inventories, the average inventory levels of the recommended ordering method must be expressed as the inventory levels for 2024.

Assuming a constant material consumption, average inventory can be determined as the average between the minimum inventory (before delivery) and the maximum inventory (after delivery), meaning that the average inventory is equal to the sum of the maximum and minimum inventory divided by two. To determine the average amount of capital tied up in inventories for individual years, the average inventory sizes need to be multiplied by the purchase price.

Table 4. Main Inventory ABC Analysis Results

Sequence No	Material	Inventory	Cumulative Inventory	Cumulative %	Class
1	M11	560	560	28,81	A
2	M9	224	784	40,33	A
3	M12	200	984	50,62	A
4	M13	144	1128	58,02	A
5	M14	128	1256	64,61	A
6	M2	120	1376	70,78	A
7	M3	120	1496	76,95	A
8	M6	100	1596	82,10	B
9	M4	80	1676	86,21	B
10	M7	72	1748	89,92	B
11	M5	60	1808	93,00	B
12	M1	48	1856	95,47	C
13	M8	48	1904	97,94	C
14	M10	40	1944	100,00	C

Table 5. Main Inventory ABC Analysis Results

Sequence No	Material	Inventory	Cumulative Inventory	Cumulative %	Class
1	M11	330	330	22,04	A
2	M12	314	644	43,02	A
3	M9	170	814	54,38	A
4	M6	102	916	61,19	A
5	M13	102	1018	68,00	A
6	M14	102	1120	74,82	A
7	M10	54	1174	78,42	A
8	M1	51	1225	81,83	B
9	M2	51	1276	85,24	B
10	M3	51	1327	88,64	B
11	M4	51	1378	92,05	B
12	M5	51	1429	95,46	C
13	M7	34	1463	97,73	C
14	M8	34	1497	100,00	C

The results of the ABC analysis are shown in the table below. As is well known, items are classified as A up to 80% of the total value, B up to 95%, and C up to 100%.

Table 6. Main Inventory ABC Analysis Results

Sequence No	Material	Inventory	Cumulative Inventory	Cumulative %	Class
1	M11	396	396	22,06	A
2	M12	377	773	43,06	A
3	M9	204	977	54,43	A
4	M6	122	1099	61,23	A
5	M13	122	1221	68,02	A
6	M14	122	1343	74,82	A
7	M10	65	1408	78,44	A
8	M1	61	1469	81,84	B
9	M2	61	1530	85,24	B
10	M3	61	1591	88,64	B
11	M4	61	1652	92,03	B
12	M5	61	1713	95,43	C
13	M7	41	1754	97,72	C
14	M8	41	1795	100,00	C

Findings and Discussion

Inventory analysis and control have become indispensable for the manufacturing industry. To prevent stockouts, it is crucial to stay up to date with the quantity and condition of items in a specific inventory. In this context, both periodic and continuous techniques can be used to evaluate inventory statistics. Once the numbers are accurately determined, it is also important to further identify at which level a specific item's stock should be maintained. For this, calculations and analyses are essential.

The study found that the priorities of items change according to different inventory analysis techniques. Company management decides which process to follow, taking into account factors such as their budget, supply, demand, inventory carrying capacity, etc.

As a result, based on the analysis conducted in this research, the client company has the opportunity to optimize its inventory for the selected products included in the study. This will maintain the expected customer service levels and will not result in any significant changes in the relevant field. If this study is not time-constrained and conducted full-time, more specific answers to the research questions can be obtained, and a clearer understanding of which category each item belongs to can be achieved through a detailed product description for each item.

The client company will need to calculate the optimal quantity of products to be stocked. Perhaps, with specialized focus, a combination of cost-effectiveness and time availability, in a more concentrated study, the results of the research would reveal even the smallest details.

Lastly, as the product coding issue has been raised, it would be beneficial for the client company to allocate resources to investigate these product coding issues, as they may prove useful for their daily operations.

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ANALYSIS OF ELECTRICAL CHARACTERISTICS OF SILVER AND GOLD NANOPARTICLES INTERFACE LAYERS ON SILICON AT SCHOTTKY DIODES

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ABSTRACT
In this study, spin-coating is used method for depositing gold nanoparticles (Au NPs) and silver nanoparticles (Ag NPs) on n-Si substrate. The current-voltage (I-V) measurements were performed for the Au/Au NPs/n-Si/Al and the Au/Ag NPs/n-Si/Al structures to understand the effect of Au NPs and Ag NPs on electrical properties at room conditions. The characteristic device parameters such as the barrier height (Φ_b), the ideality factor (n), the rectification ratio (RR), and the series resistance (R_s) were obtained to using thermionic emission and cheung function for discussed in details. The capacitance-voltage (C-V) characteristics of these devices were investigated at 500 kHz at room temperature. The results show that metal nanoparticles (NPs) on metal-Si (MS) interface is an alternative method for modification of schottky barrier height to using in a variety of optoelectronic applications.
Keywords: Au (gold) NPs; Ag (silver) NPs; barrier inhomogeneity; schottky; semiconductor

1. INTRODUCTİON

Silicon (Si) has been the best option for many electronic devices owing to the abundance, availability and high purity single crystal [1]. Organic [2] and inorganic [3] are used interfacial thin layer (other than the Si oxide layer) at MS interface for interface states modification. The incorporation of nanoparticles at the interface between the metal and semiconductor is alternative method to schottky that do not involve any heat treatment step or increasing the doping concentration [4]. In this method, the interface metal NPs improve the electric field that reduces barrier height and hence increases the field emission (FE) conduction at the metal-Si (MS) interface. In addition, semiconductor with metal nanoparticles have been considered recently to be more advantageous in many aspects [5,6]. Metal nanoparticles with high work function can enhance current and lower their operation voltages. Especially, gold and silver nanoparticles have been widely researched than other metal nanoparticles [7,8]. When a light is incident on a metal surface, collective vibration of free electrons occurs due to the electric field of the light [9].This collective vibration of free electrons is called plasmon [10].Nano-sized metal particles generate plasmon on the particle surface and this is called surface plasmon [11]. The surface plasmon resonates with light of a specific frequency coming from the outside, which generates a strong electric field around the metal particle [11]. Performance and reliability of these Schottky-type diodes depend on the formation of an interfacial layer and its effects on the diode as the interface states distribution at the interfacial layer and the semiconductor, and inhomogeneous barrier heights together with parasitic resistances. The aim of this study is to investigate electrical properties of Au/Au NPs/n-Si/Al and the Au/Ag NPs/n-Si/Al devices were analyzed by using current-voltage (I-V) and capacitance-voltage (C-V) measurements.

2. MATERİALS AND METHODS

N-type Si substrates 400 μm thick with resistivity of ~ 1-10 Ωcm were used to fabricate these Schottky devices. Silver (Ag) and Gold (Au) nanoparticle were supplied from Sigma-Aldrich Ltd. Gold and Silver nanoparticles (Au NPs) are an average size of 5 nm. The n-Si wafer was cleaned using acetone, methanol and the RCA cleaning procedure for eliminate the impurities and native oxide layer [12,13]. Aluminum (Al) metal with a thickness of 60 nm was thermally evaporated to the all back surface of the Si layer and the wafer annealed at 450^{o}C for 5 min in N_2 gas to form ohmic contacts. The silver (Ag) and gold (Au) nanoparticle solutions were coated on Si substrates by the spin coating technique at a spinning rate of 3000rpm for 50 seconds in an atmosphere. After this coating process, Au metal was formed on thin film by thermal evaporating. The *I-V* and the *C-V* measurements of Au/Au NPs/n-Si/Al and the Au/Ag NPs/n-Si/Al devices were achived by a KEITHLEY 2400 Picoammeter/Voltage Source and HP 4192A (50 Hz-13MHz) LF IMPEDANCE ANALYZER, respectively.

3. RESULTS AND DİSCUSSİONS

The I-V curves of the Au/Au NPs/n-Si/Al and Au/Ag NPs/n-Si/Al devices at room temperatures are shown in Fig. 1. These devices parameters were obtained from I-V characteristic. The experimentally obtained measurements are analyzed with the standard thermionic emission theory and can e expressed by the following formulas [14]:

$$I=I_0\,[exp\,((V-IR_s)/nkT-1)] \quad \textbf{(1)}$$

$$I_0=AA^{*}T^{2}exp\,(-q\Phi_b/kT) \quad \textbf{(2)}$$

is the saturation current, A effective diode area, A* the Richardson constant and equals to 112 A cm^{-2} K^{-2} for n-type Si, T the temperature in Kelvin, Φ_b is the effective barrier height at zero bias, q is the electron charge, V is the bias voltage, kis Boltzmann constant, n is the ideality factor. The I_0 value is used to determine the barrier height of the Schottky diode and the I_0 value is determined from the point where the ln I-V graph intersects the axis at V= 0 in the direct bias section. If Eq 2 is rewritten, Eq 3 is obtained for the barrier height expression.

$$q\Phi b=(AA^{*}T^{2}/I0) \quad \textbf{(3)}$$

The ideality factor (n) is found from the slope of the linear part of the ln I-V graph in the direct feed region and is given by the expression Eq.4.

$$n=(q/kT)dV/d(lnI) \quad \textbf{(4)}$$

The ideality factor and barrier height are 2.98 and 0.70eV for Au/Au NPs/n-Si/Al, are 3.61 and 0.69eV for Au/Ag NPs/n-Si/Al, respectively. This change in the ideality factor of devices may be explained the presence of series resistance, the presence of interface states, barrier non-homogeneity, and the presence of the film layer in the interface [15]. The rectification ratio (RR) of the Au/Ag NPs/n-Si/Al and Au/Au NPs/n-Si/Al diodes were determined as 1710 and 4278 under the dark condition, respectively from I-V plots.

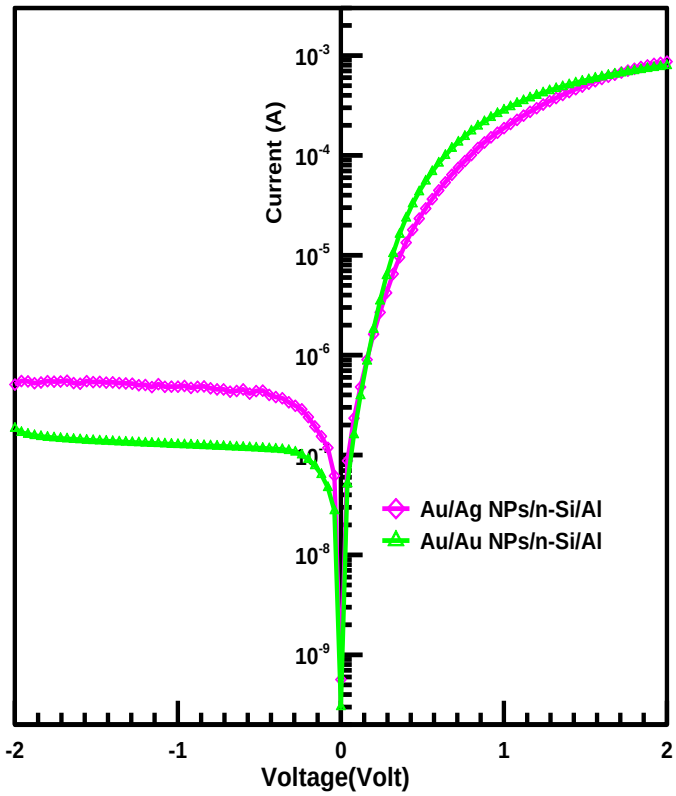

Fig.1 The I-V plots of Au/Au NPs/n-Si/Al and Au/Ag NPs/n-Si/Al device under the dark conditions (at room temperature).

Capacitance-voltage (C-V) measurement is an another important method that can provide information about the donor carrier concentration (N_d), barrier heights (Φ_b), fermi energy level (E_f) and diffusion potential (V_d) parameters. Under the dark and room conditions, capacitance-voltage (C-V) and reverse bias $1/C^2$-V plots of the Au/Au NPs/n-Si/Al and Au/Ag NPs/n-Si/Al devices are shown in Fig.2 (a,b) at 500kHz. The values of V_d, Φ_b, N_{dop} and E_f were calculated from the reverse bias C^{-2}-V plots for both the devices and tabulated in Table 1. With increasing voltage, frequency values reach a maximum value for all the device produced. The capacitance value of the Au/Au NPs/n-Si/Al device is higher than the Au/Ag NPs/n-Si/Al device. In the case of reverse bias, the value of the capacitance increases monotonically at negative voltages whereas the value of the capacitance increases towards the high voltages in forward bias.

Table 1
The experimental results determined from the C^{-2}-V plots.

Device	V_d(V)	E_f(eV)	N_d(cm^{-3}) $\times 10^{15}$	Φ_b(eV)
Au/Au NPs/n-Si/Al	0.48	0.26	1.17x10^{15}	0.74
Au/Ag NPs/n-Si/Al	0.53	0.22	4.18x10^{15}	0.76

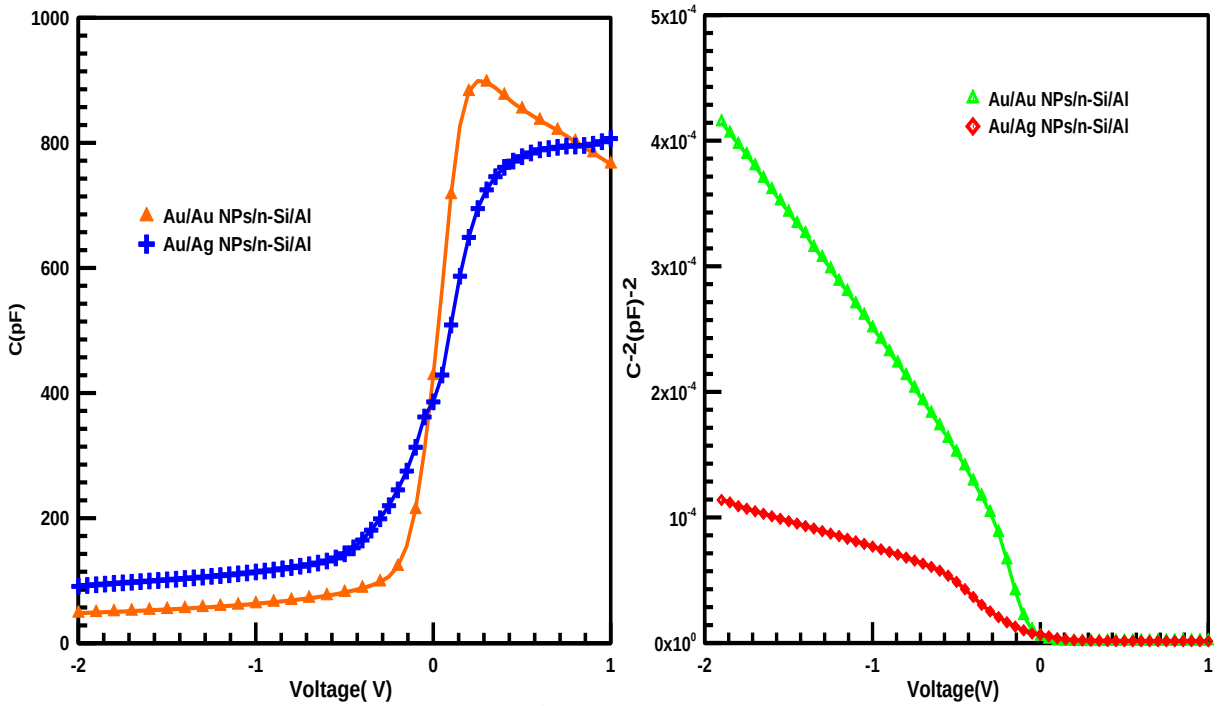

Fig. 2 The *C-V* **(a)** and reverse bias $1/C^2$-V**(b)** plots of the Au/ Ag NPs/n-Si/Al and Au/Au NPs/n-Si/Al devices (500 kHz applied frequency) at room temperature.

4. CONCLUSIONS

Au/ Ag NPs/n-Si/Al and Au/Au NPs/n-Si/Al devices were fabricated and the device parameters such as the ideality factor and the barrier height calculated with current- voltage (I-V) for two devices. The electrical parameters of these devices have been investigated using capacitance-voltage (*C-V*) measurements and the *C-V* characteristics revealed that the Au NPs layer affected strongly the capacitance behaviors as well as some other electrical parameters such as V_d, Φ_b, N_d and E_f values. The obtained diodes exhibited good rectifying properties, and their electrical values changed with silver nanoparticle (Ag NPs) and gold nanoparticle (Au NPs). In summay, we showed the possibility to fabricate MIS device using gold nanoparticle and silver nanoparticle at the room temperature. According to the electrical parameters, the fabricated devices can be improved for optoelectronic applications.

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İÇTEN YANMALI BİR MOTORDA CNG KULLANIMININ PERFORMANS PARAMETRELERİNE ETKİSİ VE TEORİK MODELLENMESİ

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ÖZET

Günümüzde kentleşmenin hızla artmasıyla birlikte, motorlu taşıtlardan kaynaklanan egzoz emisyonları önemli bir çevre sorunu haline gelmiştir. Özellikle büyükşehirlerdeki yoğun araç trafiği ve toplu taşıma filolarında yaygın olarak kullanılan dizel yakıt, çevre kirliliğini tetikleyen başlıca unsurlar arasında yer almaktadır. Bu çerçevede, düşük karbon salımı, yüksek verimlilik ve çevresel sürdürülebilirlik açısından öne çıkan sıkıştırılmış doğal gaz (CNG), geleneksel yakıtlara alternatif bir enerji kaynağı olarak dikkat çekmektedir. Son yıllarda ülkemizin keşfettiği doğal gaz rezervleri de bu yakıtın daha yaygın kullanımı açısından önemli bir potansiyel sunmaktadır. Bu çalışmada, dört zamanlı içten yanmalı motorlarda alternatif yakıt olarak kullanılan CNG'nin motor performansı ve egzoz emisyonlarına etkileri teorik yaklaşımlarla incelenmiştir. İstanbul'da toplu taşımada hizmet veren Karsan marka 12 metrelik otobüslerde kullanılan altı silindirli CNG motoru esas alınarak, dizel ve CNG yakıtlarının performans karakteristikleri karşılaştırmalı olarak değerlendirilmiştir. Yanma odası geometrisi, piston yapısı, supap mekanizması ve enjeksiyon sistemine dair parametreler dikkate alınarak, motorun teorik modeli oluşturulmuş; indike güç, efektif güç, yanma sonu sıcaklıkları ve emisyon değerleri hesaplanmıştır. Bununla birlikte, Diesel-RK yazılımı ile simülasyon analizleri gerçekleştirilerek dizel ve CNG motorlarının teorik verileri elde edilmiştir. Yakıt ekonomisi analizi kapsamında ise maksimum güç ve tork koşullarında birim araç ve filo bazında tüketim değerleri dikkate alınarak sağlayabileceği ekonomik ve çevresel katkılar hesaplanmıştır. Çalışma sonucunda, CNG kullanımının geleneksel dizel yakıtlara göre sağladığı avantajlar teorik verilerle ortaya konulmuş ve Paris İklim Anlaşması hedefleri doğrultusunda somut öneriler geliştirilmiştir.

Anahtar Kelimeler: Sıkıştırılmış Doğal Gaz, İçten Yanmalı Motorlar, Egzoz Emisyonu, Yakıt Ekonomisi

THEORETICAL MODELING AND PERFORMANCE EFFECTS OF CNG USAGE IN AN INTERNAL COMBUSTION ENGINE

ABSTRACT

With the rapid growth of urbanization, exhaust emissions from motor vehicles have become a significant environmental issue. In particular, the intensive use of diesel fuel in public transportation fleets operating in metropolitan areas is one of the leading causes to increasing air pollution. In this context, compressed natural gas (CNG), which stands out with its low carbon emissions, high efficiency, and environmental sustainability, has attracted attention as an alternative energy source to conventional fuels. Moreover, the recent discovery of natural gas reserves in our country highlights the potential for its widespread use, especially in public and heavy-duty transportation systems.

In this study, the effects of CNG—used as an alternative fuel in four-stroke internal combustion engines—on engine performance and exhaust emissions are examined through theoretical approaches. A six-cylinder CNG engine used in 12-meter Karsan buses operating in Istanbul's public transportation network was taken as a reference, and a comparative evaluation of the performance characteristics of diesel and CNG fuels was conducted. Considering parameters such as combustion chamber geometry, piston structure, valve mechanism, and injection system, a theoretical model of the engine was developed, and values such as indicated power, effective power, end-of-combustion temperatures, and emission outputs were calculated.

In addition, simulation analyses were carried out using the Diesel-RK software to obtain the theoretical performance data of both diesel and CNG engines. As part of the fuel economy analysis, fuel consumption values were evaluated under maximum power and torque conditions on both unit vehicle and fleet scales, in order to assess the potential economic and environmental benefits. As a result, the advantages of CNG over conventional diesel fuel were demonstrated through theoretical data, and concrete recommendations were proposed in line with the objectives of the Paris Climate Agreement.

Keywords: Compressed Natural Gas, Internal Combustion Engines, Emissions, Fuel Economy

1. GİRİŞ

Günümüzde fosil yakıt kullanımına bağlı olarak artan sera gazı emisyonları, çevresel sürdürülebilirlik açısından ciddi bir tehdit oluşturmaktadır. Özellikle büyük şehirlerde yoğun olarak kullanılan dizel motorlu araçlar, karbondioksit (CO_2), azot oksitler (NO_x) ve partikül madde (PM) salınımları nedeniyle hava kalitesini olumsuz yönde etkilemektedir. Bu bağlamda, daha temiz ve ekonomik alternatif yakıt arayışları hem akademik çevrelerde hem de kamu politikalarında öncelikli konular arasında yer almaktadır. Sıkıştırılmış Doğal Gaz (CNG), düşük karbon içeriği ve yüksek oktan sayısı sayesinde çevre dostu bir alternatif olarak öne çıkmaktadır. Literatürde yapılan çeşitli çalışmalarda, CNG'nin dizel yakıta kıyasla %25 ila %30 oranında daha düşük CO_2 emisyonuna sahip olduğu, aynı zamanda NO_x ve PM salınımlarını da önemli ölçüde azalttığı belirtilmektedir (Altın & Pamir, 2017; Çanakçı, 2020).

Bu çalışmanın temel amacı, buji ateşlemeli içten yanmalı motorlarda CNG kullanımının performans üzerindeki etkilerini teorik ve uygulamalı yöntemlerle incelemektir. Bu kapsamda, İstanbul Büyükşehir Belediyesi'ne bağlı İETT otobüs filosu özelinde dizelden CNG'ye geçişin çevresel ve ekonomik sonuçları değerlendirilmiş, elde edilen veriler ışığında karşılaştırmalı analizler yapılmıştır. CNG'nin yüksek oktan sayısı (120–130), daha yüksek sıkıştırma oranları ile çalışmaya olanak tanımakta ve bu durum daha verimli bir yanma süreci ile sonuçlanmaktadır. Bununla birlikte, CNG'nin motor içi sıcaklıkları düşürdüğü ve motor ömrünü uzattığı da çeşitli çalışmalarla ortaya konmuştur (Demirbaş & Şen, 2017; Yıldırım & Ünal, 2018). Ayrıca, literatürde CNG ile çalışan motorlarda tork ve güç değerlerinde iyileşmelerin gözlemlendiği ve silindir içi basınç, sıcaklık ve emisyon karakteristikleri açısından daha çevreci bir profil sunduğu ifade edilmektedir (Sönmez, 2017; Özcan, 2010; Sahoo, 2021).

Analiz sürecinde, Diesel-RK programı kullanılarak dört zamanlı buji ateşlemeli bir motorun matematiksel modeli oluşturulmuş, hem dizel hem de CNG yakıtı için motor içi yanma karakteristikleri ve performans parametreleri detaylı şekilde incelenmiştir. Elde edilen sonuçlar doğrultusunda, CNG'nin sadece emisyon açısından değil, aynı zamanda yakıt tüketimi ve verimlilik yönünden de şehir içi taşımacılıkta sürdürülebilir bir alternatif oluşturduğu görülmektedir. İETT filosundaki uygulama örnekleri ve diğer uluslararası çalışmalar, CNG'nin toplu taşımada kullanımının yakıt tüketiminde %30'a varan tasarruflar sağladığını, bakım maliyetlerini düşürdüğünü ve sessiz çalışma gibi operasyonel avantajlar sunduğunu göstermektedir (Tuna & Soylu, 2017; Kara & Yıldız, 2019; Nguyen, 2021; Supee, 2014). Bu bağlamda, çalışma sonuçları, CNG'nin içten yanmalı motorlarda hem performans hem de çevresel kriterler açısından önemli bir alternatif yakıt olduğunu ortaya koymaktadır.

2. ARAŞTIRMA VE BULGULAR

2.1. Motorun Gerçek Çevrimi ve Analiz Yaklaşımı

Motor performansının teorik olarak analizinde sıklıkla ideal çevrimler kullanılmakla birlikte, bu çevrimler belirli varsayımlara dayandığından gerçek çalışma koşullarını tam anlamıyla yansıtmazlar. Oysa gerçek çevrim analizleri, motorun çalışması sırasında ortaya çıkan tüm fiziksel etkileri dikkate alarak daha doğru ve güvenilir sonuçlar sunar. Bu analizlerde; ısı transfer kayıpları, mekanik sürtünmeler, gaz değişim süreçlerinde yaşanan kayıplar, ateşleme ve yanma gecikmeleri ile yanmanın süre ve şiddetindeki değişkenlik gibi parametreler hesaba katılır. Bu yönüyle gerçek

çevrim modellemesi, yakıt türü ve çevresel koşullar gibi faktörlerin motor verimliliği ve emisyonlar üzerindeki etkilerini değerlendirmek için etkili bir yöntem sunmaktadır.

Bu çalışmada, motorun gerçek çevrim analizi için fiziksel temelli bir ileri mühendislik aracı olan Diesel-RK yazılımı kullanılmıştır. Diesel-RK, dört zamanlı içten yanmalı motorlarda hem yanma sürecini hem de gaz alışverişini yüksek hassasiyetle modelleyebilme yeteneğine sahiptir. Simülasyon sürecinde, motorun temel geometrik özellikleri (silindir çapı, strok, sıkıştırma oranı), kullanılan yakıtların karakteristikleri (CNG ve dizel yakıtların alt ısıl değerleri, kimyasal bileşimi), ısı salım modelleri, yanma süreleri ve termodinamik verimlilik gibi parametreler detaylı biçimde tanımlanmıştır. Aynı zamanda, egzoz emisyonları (CO_2, NO_x vb.) ve özgül yakıt tüketimi gibi çıktılar analiz edilerek elde edilen simülasyon sonuçları teorik beklentilerle karşılaştırılmış, böylece CNG ve dizel yakıtların motor üzerindeki etkileri hem performans hem de çevre açısından değerlendirilmiştir.

Uygulama açısından, İstanbul Büyükşehir Belediyesi'ne bağlı İETT otobüs filosu bu araştırmanın örneklem alanını oluşturmaktadır. Türkiye'de artan araç sayısı ve buna bağlı çevresel kaygılar, alternatif yakıt arayışlarını hızlandırmış ve bu kapsamda CNG, toplu taşımada öne çıkan bir seçenek haline gelmiştir. İETT bünyesinde hâlihazırda hizmet veren 346 adet CNG'li otobüs, özellikle çevresel hassasiyetin yüksek olduğu kent içi güzergâhlarda kullanılmaktadır. Bu araçlar ile dizel muadilleri arasında yapılan karşılaştırmalarda, CO_2 ve NO_x emisyonlarında belirgin düşüşler tespit edilmiştir.

İstanbul'daki CNG altyapısının merkezinde ise Kağıthane CNG istasyonu yer almaktadır. İETT'ye ait bu tesis, beş kompresör, üç jeneratör, kırk adet tüp, sekiz dağıtım ünitesi (dispenser) ve çift kademeli kurutma sisteminden oluşan modern bir dolum altyapısına sahiptir. Maksimum 26 MPa dolum basıncı ile 7.500 Nm^3/saat kapasiteye ulaşabilen istasyon, gelişmiş yangın algılama ve gaz sızıntısı tespit sistemleriyle güvenlik standartlarını da en üst seviyede karşılamaktadır. Bu altyapı, CNG'li otobüslerin sürdürülebilir ve güvenli biçimde operasyonel faaliyetlerini sürdürebilmesini mümkün kılmaktadır.

Sıkıştırılmış doğal gaz (CNG), çoğunlukla metan (CH_4) gazından oluşan ve genellikle 20–25 MPa basınç altında depolanan alternatif bir yakıt türüdür. CNG, düşük karbon içeriği ve yüksek hidrojen oranı sayesinde, çevre dostu yakıtlar arasında önemli bir konuma sahiptir. Özellikle içten yanmalı motorlarda kullanımında, egzoz emisyonlarını azaltması ve yüksek oktan sayısı sayesinde vuruntuya karşı direnç göstermesi açısından dikkat çekmektedir. Bu özellikleri, CNG'nin hem çevresel etkilerini azaltmasını hem de motor performansına olumlu katkı sunmasını mümkün kılmaktadır.

CNG'nin fiziksel ve kimyasal özellikleri, yanma verimi ve motor davranışları üzerinde doğrudan etkili olmaktadır. Yüksek oktan sayısı sayesinde daha yüksek sıkıştırma oranları ile çalışmaya olanak tanıyan CNG, dizel ve benzin gibi geleneksel yakıtlarla karşılaştırıldığında daha temiz bir yanma süreci sunar. Bununla birlikte, CNG'nin düşük yoğunluğu ve enerji içeriği, hacimsel olarak daha fazla yakıt tüketimine yol açabilmektedir. Ancak modern enjeksiyon sistemleri ve motor yönetim teknolojileri ile bu dezavantajlar büyük ölçüde minimize edilebilmektedir. Aşağıda, CNG'nin bazı temel yakıt özelliklerini özetleyen tablo sunulmuştur:

Tablo 2.1. CNG Yakıt Özellikleri

Özellik	Değer	Açıklama
Kimyasal bileşim	~%90–97 CH_4	Metan ağırlıklı, az miktarda etan, propan, CO_2 içerir
Alt ısıl değer (LHV)	~47.5 MJ/kg	Yüksek enerji içeriği, yanma verimini etkiler
Yoğunluk (15°C, 1 atm)	~0.72 kg/m³	Hacimsel enerji yoğunluğu düşüktür
Oktan sayısı (RON)	120–130	Yüksek sıkıştırma oranlarına uygundur
Stoichiometrik hava-yakıt oranı (AFR)	17.2:1	Benzin ve dizelden daha yüksek hava gereksinimi
Alev hızı	0.38–0.45 m/s	Kontrollü ve yavaş yanma süreci
Alev sıcaklığı	1950–2050 °C	Benzine benzer, dizelden düşük
Tutuşma sıcaklığı	~540 °C	Güvenlik açısından daha avantajlı
CO_2 emisyon potansiyeli	Dizele göre %25–30 daha az	Düşük karbon içeriğine bağlı

Gerçek çevrim analizinde kullanılan başlıca denklemler, termodinamik yasaların motor çalışma döngüsüne uygulanmasıyla elde edilir. İlk olarak, enerji dengesi denklemine dayanan **ilk yasa (enerji korunumu**) motorun her çevrimde ne kadar iş ürettiğini belirlemek için kullanılır. Silindir içerisindeki gazın durumu, ideal gaz varsayımı altında ya da gelişmiş karışım modelleriyle aşağıdaki temel ifadelerle tanımlanabilir:

$$pV^n = const.$$

Bu denklem, sıkıştırma ve genleşme süreçlerinde kullanılan polytropik yaklaşımı temsil eder. Burada p basınç, V hacim ve n ise politropik katsayıdır. Gerçek motorlarda yanma sırasında enerji salımı, sabit hacimde veya sabit basınçta gerçekleşmez; bu nedenle **Wiebe fonksiyonu** gibi ampirik modeller tercih edilir. Wiebe fonksiyonu, yanma sürecinin zaman içerisindeki gelişimini matematiksel olarak ifade eder:

$$x_b(\theta) = 1 - exp[-a\left(\frac{\theta - \theta_0}{\Delta\theta}\right)^m]$$

Burada x_b yanmış gaz oranı, θ krank açısı, θ_0 yanmanın başladığı açı, Δθ yanma süresi, a ve m ise şekil katsayılarıdır. Bu parametreler, CNG ve dizel gibi farklı yakıtların yanma özelliklerine göre kalibre edilir. Örneğin, CNG'nin düşük alev hızına karşılık daha uzun bir yanma süresi öngörülürken, dizel yakıtta bu süre daha kısa ve yüksek basınç altında gerçekleşir.

Isı transferi, özellikle yanma sonrası sıcak gazların silindir cidarına etkisiyle önemli enerji kayıplarına neden olur. Bu süreç genellikle **Woschni ısı transfer modeli** ile temsil edilir:

$$h = C_1 p^{0.8} T^{-0.55} w^{0.8}$$

Burada h ısı transfer katsayısı, p silindir içi basınç, T sıcaklık ve w ortalama gaz hızıdır. CNG'nin daha düşük alev sıcaklığı ve farklı gaz özellikleri nedeniyle ısı transferi dinamikleri dizel motora kıyasla farklılık göstermektedir.

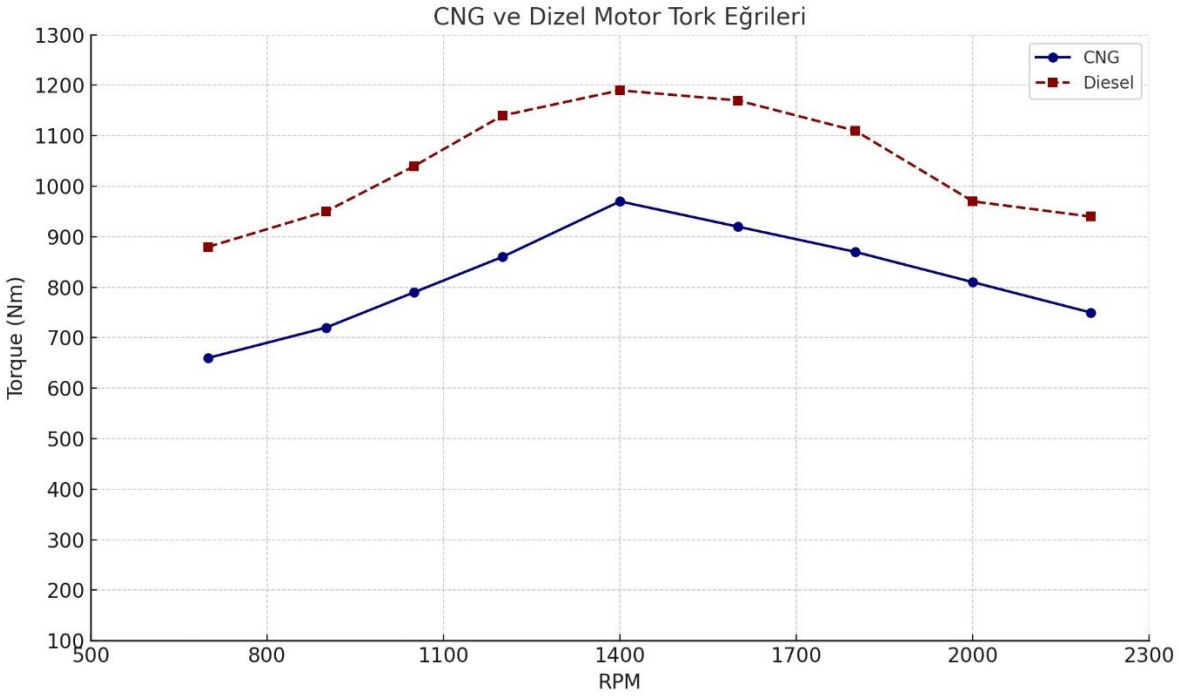
Ayrıca, emme ve egzoz sürecinde oluşan pompalama kayıpları da motor verimliliğini doğrudan etkiler. Bu süreçler, valf zamanlamaları ve akış katsayılarına bağlı olarak modellenir. Diesel-RK programı bu kayıpları, isentropik olmayan akış denklemleri ve gaz dinamiği prensipleri ile simüle eder.

2.2. Analiz ve Sonuçlar

Analizlerde kullanılan motorların özellikleri ve alınan parametreler aşağıdaki tabloda yer almaktadır ;

Tablo 2.2. Analizde Kullanılan Motor Parametreleri

Parametre	CNG Motor (Avancity)	Dizel Motor (Avancity)
Motor Tipi	OM 906 LAG (CNG)	OM 906 LA (Dizel)
Silindir Sayısı	6	6
Silindir Çapı (mm)	102	108
Strok (mm)	130	130
Motor Hacmi (cm³)	6830	6374
Sıkıştırma Oranı	12	17,4
Nominal Güç (kW)	205	205
Nominal Güç RPM	2200	2300
Maksimum Tork (Nm)	1000	1100
Tork Maks RPM	1400	1250
Yakıt Türü	CNG	Dizel
Alt Isıl Değer (MJ/kg)	47,5	42,7
Stoichiometrik Hava/Yakıt Oranı	17,2	14,6
Oktan/Setan Sayısı	120	50
Adyabatik Alev Sıcaklığı (K)	1890	2054
Alevlenme Sınırı (%)	4.3–15.2	1–6
Laminer Alev Hızı (m/s)	0,41	
Emme Valfi Açılış (°CA)	-10 BTDC	-15 BTDC
Emme Valfi Kapanış (°CA)	40 ABDC	35 ABDC
Egzoz Valfi Açılış (°CA)	130 BBDC	120 BBDC
Egzoz Valfi Kapanış (°CA)	5 ATDC	10 ATDC
Ateşleme Başlangıcı (°CA)	10 BTDC	5 BTDC
Yakıt Püskürtme Süresi (°CA)	30	25
Çevre Sıcaklığı (K)	298	298
Atmosfer Basıncı (bar)	1,013	1,013
Emme Manifold Basıncı (bar)	1	1,4
Emme Havası Sıcaklığı (K)	310	315
Egzoz Basıncı (bar)	1,05	1,1
Soğutma Suyu Sıcaklığı (K)	370	380
Motor Sürtünme Katsayısı	0,1	0,12
Termal Verim Başlangıç Tahmini (%)	38	40
Turbo Boost Basıncı (bar)	1,4	1,6
Intercooler Verimi (%)	75	70
Turbo Verimi (%)	68	65
Egzoz Gazı Karşı Basıncı (bar)	1,3	1,5
Turbo Giriş Sıcaklığı (°C)	780	820

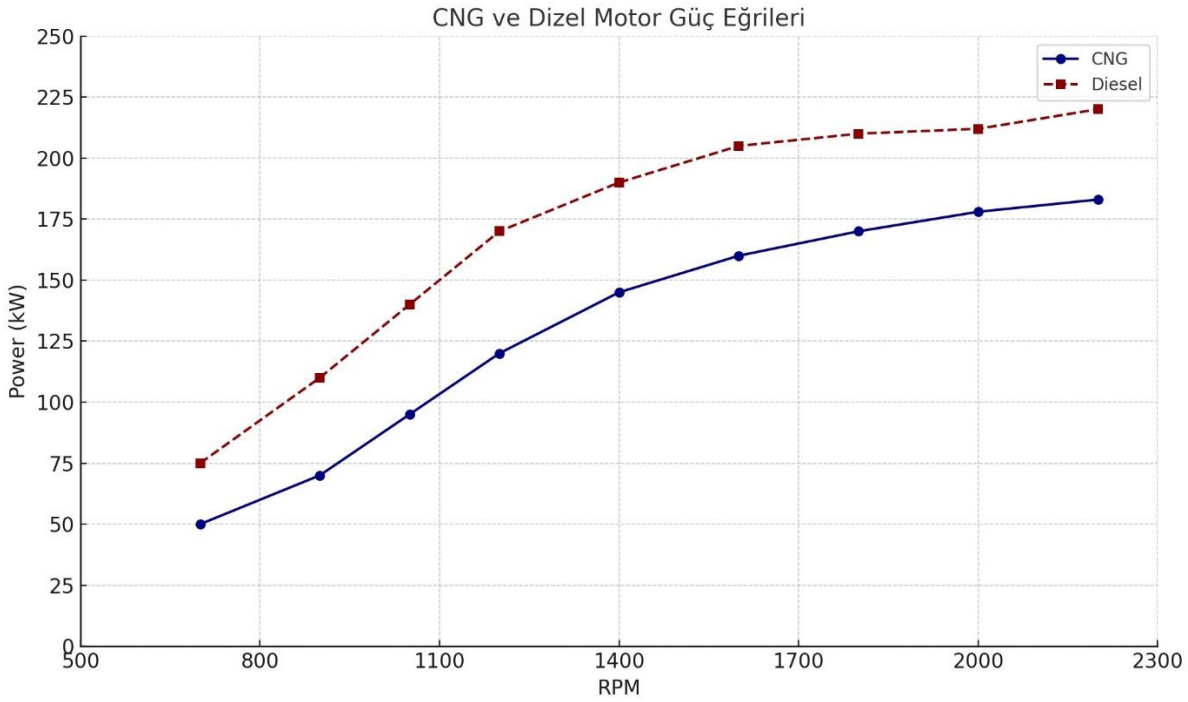


Şekil 2.1. Motor Tork Değişimi

Şekilde sunulan grafik, CNG ve dizel yakıtlı motorların tork karakteristiklerini aynı eksen sisteminde karşılaştırmalı olarak göstermektedir. Elde edilen verilere göre, dizel motorun maksimum tork değeri yaklaşık **1190 Nm** ile **1400 devir/dakika** civarında elde edilirken, CNG motoru ise maksimum **970 Nm** torku yine benzer motor devrinde üretmektedir. Bu durum, dizel yakıtın enerji yoğunluğunun daha yüksek olması ve sıkıştırma-ateşleme prensibiyle çalışmasından kaynaklı olarak daha yüksek tork üretimine olanak tanıdığını göstermektedir.

Grafikte dikkat çeken bir diğer önemli nokta, dizel motorun tork eğrisinin **daha erken devirlerde daha dik bir şekilde yükselmesi** ve geniş bir devir bandında yüksek tork üretebilmesidir. Bu özellik, özellikle ağır vasıta ve şehir içi toplu taşıma gibi uygulamalarda kalkış performansı ve yük altında çalışma açısından avantaj sağlar. Öte yandan, CNG motorunun tork eğrisi daha yumuşak bir eğimle artmakta ve zirve noktasından sonra daha düzenli bir düşüş göstermektedir. Bu durum, CNG'nin daha stabil bir yanma karakteristiğine ve yüksek oktan sayısı nedeniyle **daha kontrollü bir yanma sürecine** sahip olmasından kaynaklanmaktadır.

Her iki eğri de yaklaşık **700 ila 2200 devir/dakika** aralığında incelenmiş olup, bu bant içerisinde dizel motorun genel olarak CNG motoruna kıyasla **daha yüksek tork değerleri ürettiği** görülmektedir. Ancak, CNG motoru da birçok uygulama için yeterli tork üretimi sağlayarak, çevresel avantajlarıyla birlikte alternatif bir seçenek olarak değerlendirilebilmektedir.

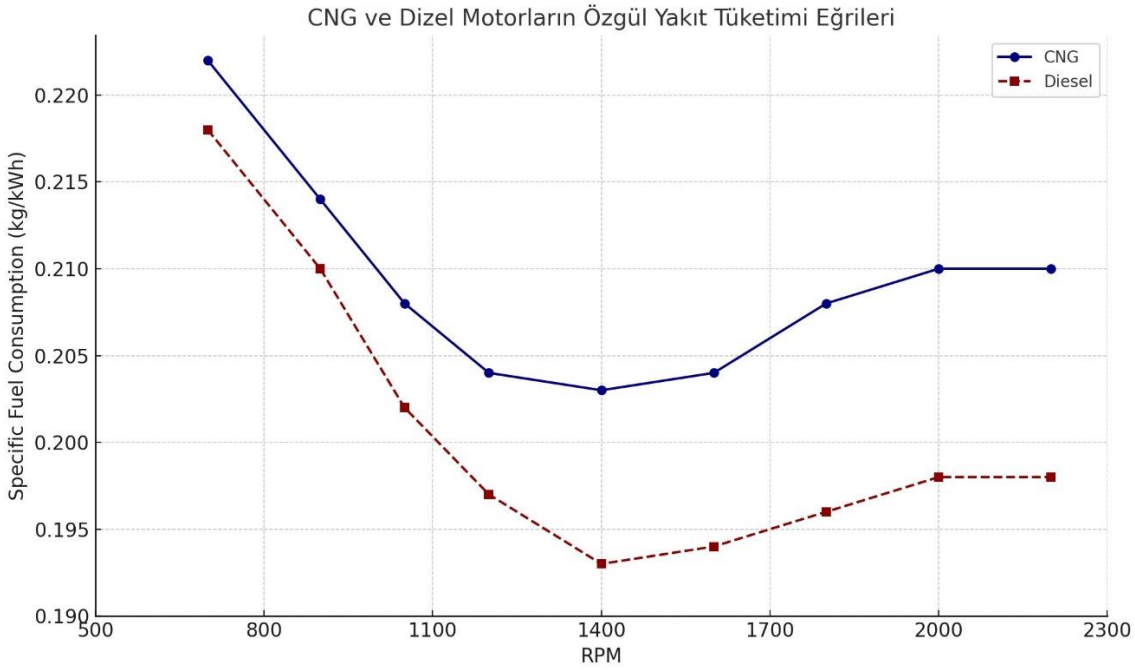


Şekil 2.2. Motor Güç Değişimi

Şekilde yer alan grafik, CNG ve dizel yakıtlı motorların devir sayısına bağlı olarak piston gücü üretimlerini karşılaştırmalı biçimde sunmaktadır. Elde edilen veriler doğrultusunda, dizel motorun CNG motoruna kıyasla tüm devir aralıklarında daha yüksek güç çıktısı sağladığı açıkça gözlemlenmektedir. Özellikle 1400 devir/dakika ve üzerindeki çalışma aralıklarında dizel motor, yaklaşık **220 kW**'a kadar güç üretirken, CNG motorun aynı devirde ulaştığı maksimum güç **yaklaşık 183 kW** seviyesindedir.

Güç eğrisinin eğimine bakıldığında, dizel motorun düşük devirlerden itibaren daha hızlı bir güç artışı sergilediği, orta devir aralığında ise bu artışın daha dengeli bir seyir izlediği görülmektedir. Bu durum, dizel motorların daha yüksek enerji yoğunluğuna sahip yakıtla çalışması ve daha güçlü bir tork karakteristiği sunmasından kaynaklanmaktadır. CNG motorlarında ise güç artışı daha lineer bir profil sergilemekte olup, yüksek devirlerde eğrinin daha yatay bir eğilim gösterdiği dikkat çekmektedir. Bu, CNG'nin yanma sürecinin daha kontrollü gerçekleşmesi ve motor yönetim sisteminin güvenli sınırlarda çalışmaya devam etme eğilimiyle açıklanabilir.

Ayrıca, her iki motorun da güç üretiminde **1400–1600 devir/dakika** aralığı kritik bir eşik olarak öne çıkmaktadır. Bu devir aralığında, motorlar maksimum tork üretimini tamamlamış ve güç çıktısını en verimli şekilde sunmaya başlamıştır. CNG motorlarında bu eşik sonrası eğri daha fazla yataylaşırken, dizel motorlar söz konusu aralıkta hâlâ artış eğilimi göstermektedir. Bu, dizel motorların daha geniş bir güç bandında verimli çalışabildiğini, dolayısıyla **yüksek tork ve güç ihtiyacı bulunan taşıma sistemlerinde** daha uygun bir seçenek olduğunu göstermektedir.

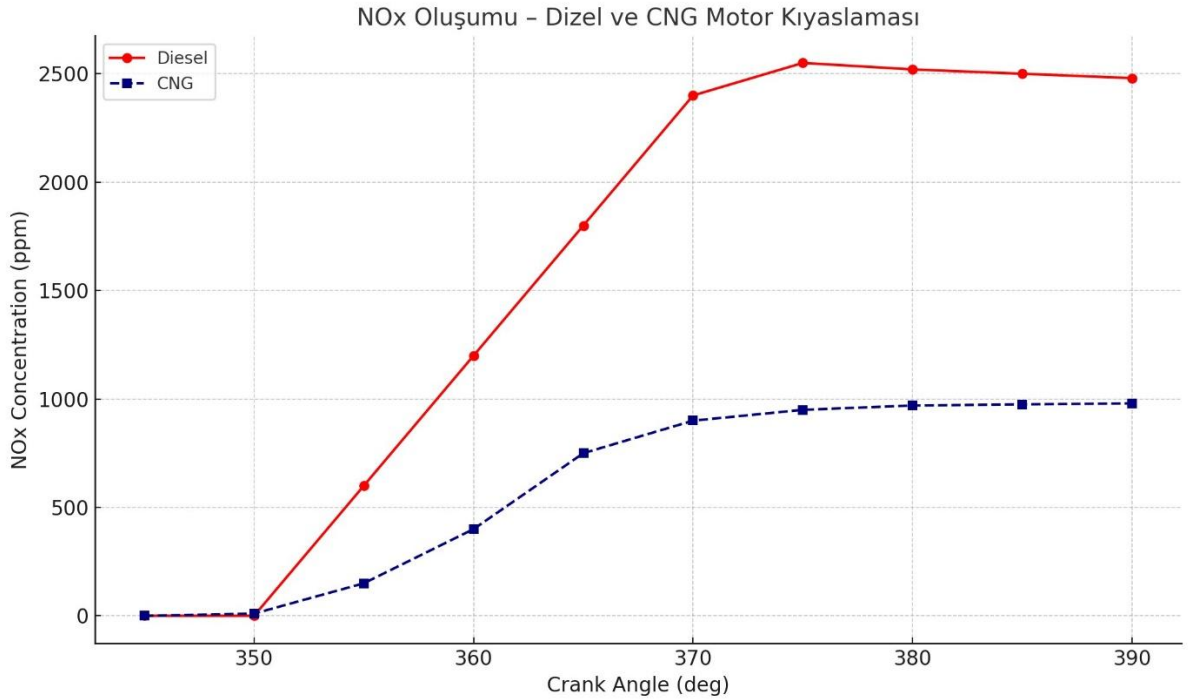


Şekil 2.3. Özgül Yakıt Tüketimi

Yukarıda sunulan grafik, CNG ve dizel yakıtlı motorların devir sayısına bağlı olarak gösterdiği özgül yakıt tüketimi (SFC - Specific Fuel Consumption) değerlerini karşılaştırmalı biçimde göstermektedir. SFC, bir motorun 1 kilovat-saat (kWh) güç üretmek için ne kadar yakıt tükettiğini (kg) ifade eden önemli bir verimlilik göstergesidir. Bu bağlamda daha düşük SFC değerleri, daha yüksek motor verimliliğine işaret eder.

Grafik incelendiğinde, her iki motor türünün de düşük devirlerden itibaren yakıt tüketimini azalttığı, **yaklaşık 1400 devir/dakika civarında minimum SFC değerine ulaştığı** görülmektedir. Dizel motor bu noktada **~0.193 kg/kWh** değeri ile en düşük özgül tüketimi sağlarken, CNG motorunda bu değer **~0.203 kg/kWh** olarak gerçekleşmiştir. Bu fark, dizel motorun yanma veriminin daha yüksek olması ve daha fazla enerji içeren bir yakıtla çalışmasından kaynaklanmaktadır.

CNG motorlarında ise özgül yakıt tüketimi daha yüksek olsa da, yanma sürecinin daha stabil gerçekleşmesi ve daha düşük egzoz emisyonları, çevresel avantajları öne çıkarmaktadır. Ayrıca, 1600 devrin üzerindeki devir aralıklarında her iki eğri de hafif bir artış göstermekte; bu durum, artan iç sürtünme, ısı kayıpları ve tam yük dışı çalışma koşullarının verimliliği olumsuz etkilemesiyle açıklanabilir.



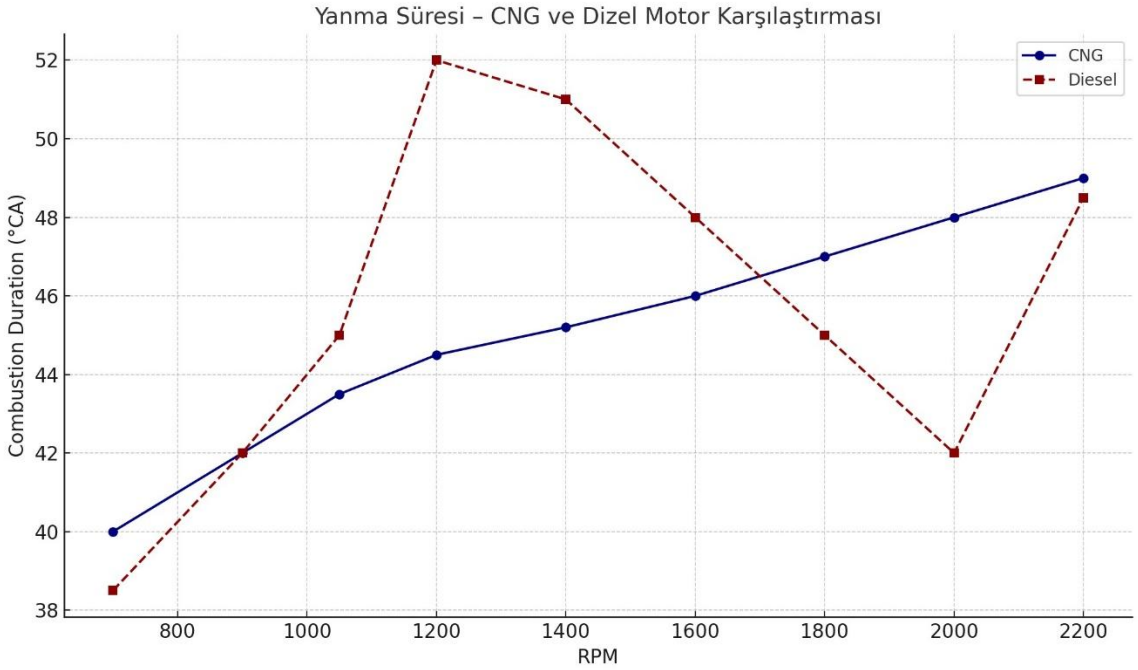
Şekil 2.4. NOx Emisyon Grafiği

Yukarıdaki grafik, dizel ve CNG motorlarında oluşan NOx (azot oksit) emisyonlarının krank açısı (CA - Crank Angle) boyunca değişimini göstermektedir. Yanma odasında sıcaklık ve oksijen konsantrasyonunun en yüksek olduğu anda oluşmaya başlayan NOx, özellikle içten yanmalı motorlarda çevresel etki açısından kritik bir parametredir. Bu bağlamda, NOx'in krank açısına göre dağılımını incelemek, hem motor verimliliği hem de emisyon kontrolü açısından önem arz etmektedir.

Grafikte görüldüğü üzere, her iki motor türü için de NOx oluşumu **yaklaşık 355°–370°** krank açısı aralığında belirgin şekilde artmaktadır. Bu aralık, genellikle yanmanın en yoğun gerçekleştiği, silindir içi basınç ve sıcaklığın maksimuma yaklaştığı zaman dilimini temsil eder. Ancak dikkat çekici fark, bu noktada dizel motorun **yaklaşık 2550 ppm** seviyesine ulaşan NOx konsantrasyonu ile CNG motoruna kıyasla çok daha yüksek emisyon üretmesidir. CNG motorunda NOx seviyesi **maksimum ~980 ppm** düzeyinde sabitlenmiştir.

Bu farkın temel nedenlerinden biri, dizel motorun daha yüksek sıkıştırma oranıyla çalışması ve silindir içindeki yanma sıcaklıklarının daha yüksek olmasıdır. NOx oluşumu sıcaklığa son derece duyarlı olduğundan, dizel motorlarda bu artış daha agresif seyretmektedir. Öte yandan, CNG motorları daha düşük alev sıcaklıklarına sahiptir ve buji ile kontrollü ateşleme sayesinde yanma daha yavaş ve homojen gerçekleşir. Bu da daha düşük NOx emisyonu ile sonuçlanır.
Krank açısı ilerledikçe (370° sonrası), her iki motorun NOx oluşumu sabitlenmekte ve eğriler plato çizmeye başlamaktadır. Bu da yanma sürecinin büyük oranda tamamlandığını ve artık sıcaklık ile oksijenin NOx oluşumuna katkısının azaldığını göstermektedir.

Sonuç olarak, dizel motorun performans açısından avantajlı olmasına rağmen, **NOx emisyonları bakımından çevreye olan etkisi oldukça yüksektir**. CNG motorları ise **daha çevreci bir yanma profili** sergilemekte ve şehir içi taşımacılıkta NOx sınırlamalarına uyum açısından önemli bir alternatif sunmaktadır.



Şekil 2.5. Yanma Süresi

Şekilde sunulan grafik, CNG ve dizel motorlarda farklı devirlerde gerçekleşen yanma sürelerinin krank açısı (°CA) cinsinden karşılaştırmalı analizini içermektedir. Yanma süresi, silindir içerisindeki karışımın ateşlenmesiyle başlayan ve enerjinin tamamının serbest kaldığı süreyi ifade eder. Bu sürenin uzunluğu, motor verimliliğini, NOx oluşumunu ve ısı transferini doğrudan etkileyen önemli bir parametredir.

Grafik incelendiğinde, CNG motorunda yanma süresinin devirle birlikte **neredeyse lineer bir artış** gösterdiği, 700 RPM'de yaklaşık **40°CA** iken, 2200 RPM civarında **49°CA**'ya kadar çıktığı gözlemlenmektedir. Bu eğilim, CNG'nin düşük alev hızına ve yüksek özgül ısı kapasitesine bağlı olarak yanmanın daha uzun sürede tamamlandığını göstermektedir. Ayrıca CNG'nin homojen karışımla çalışan bir yakıt olması nedeniyle yanmanın ilerlemesi daha kontrollü, ancak görece daha yavaş gerçekleşmektedir.

Dizel motor eğrisi ise daha dalgalı bir yapı sergilemektedir. Özellikle 1200 RPM civarında yanma süresi **52°CA** ile zirveye ulaşmakta, ardından yüksek devirlere çıkıldıkça **40–45°CA** aralığına kadar düşmektedir. Bu değişkenlik, dizel motorlarda yanmanın püskürtme zamanlamasına ve silindir içi türbülansa daha fazla bağlı olmasıyla açıklanabilir. Yüksek devirlerde püskürtme süresi kısaldığı için yanma süresi de buna bağlı olarak düşüş eğilimi göstermektedir.

3. SONUÇ

Bu çalışmada, CNG yakıtının buji ateşlemeli içten yanmalı motorlarda performans ve emisyon karakteristiklerine etkisi hem teorik hem de uygulamalı yöntemlerle kapsamlı şekilde analiz edilmiştir. Elde edilen veriler, CNG'nin özellikle çevresel sürdürülebilirlik açısından önemli avantajlar sunduğunu ortaya koymuştur. Dizel motor ile karşılaştırıldığında, CNG kullanımının CO_2, NO_x ve partikül madde (PM) salınımlarında anlamlı düşüşler sağladığı, böylece hava kalitesine olumlu katkılar sunduğu tespit edilmiştir.

NO_x emisyon eğrilerinden elde edilen analizler, dizel motorlarda NO_x konsantrasyonunun maksimum 2500 ppm düzeyine kadar çıktığını gösterirken, CNG motorlarında bu değerin 1000 ppm'in altında kaldığı gözlemlenmiştir. Benzer şekilde partikül madde üretiminin de CNG motorlarda neredeyse ihmal edilebilir seviyelerde olduğu belirlenmiştir. Bu sonuçlar, CNG'nin düşük karbonlu bir yakıt olması ve daha düşük alev sıcaklığına sahip olmasıyla ilişkilendirilmektedir.

Yanma süresi ve özgül yakıt tüketimi (SFC) verileri, CNG motorların daha uzun süreli ancak daha kontrollü bir yanma süreciyle çalıştığını göstermiştir. Her ne kadar dizel motorlar daha yüksek tork ve güç üretme kapasitesine sahip olsa da, CNG motorları bu farkı kabul edilebilir düzeyde bir performansla karşılayabilmekte ve daha düşük işletme maliyetleri ile öne çıkmaktadır. Yüksek oktan sayısı sayesinde vuruntuya karşı dayanıklılığı artan CNG, verimli yanma koşullarının sağlanmasına da katkıda bulunmuştur.

Ayrıca, motor çalışma sesi bakımından da CNG araçlarının daha düşük gürültü seviyelerine sahip olduğu, bu durumun özellikle şehir içi toplu taşımada çevresel gürültü kirliliğini azaltma potansiyeline sahip olduğu gözlemlenmiştir. İETT filosunda yer alan CNG'li otobüslerin yaygınlaştırılması, hem İstanbul'un hava kalitesi üzerinde olumlu etkiler yaratacak hem de Türkiye'nin Paris İklim Anlaşması çerçevesinde belirlediği karbon salınımı azaltma hedeflerine katkı sunacaktır.

Sonuç olarak, CNG yakıtı, motor performansında kabul edilebilir sınırlarda kalan kayıplarına karşılık; emisyon salınımlarında sağladığı ciddi düşüşler, düşük yakıt maliyeti, daha sessiz motor karakteristiği ve çevresel avantajları ile toplu taşımada sürdürülebilir bir alternatif yakıt olarak öne çıkmaktadır. Bu kapsamda, CNG'nin özellikle metropollerde kullanılan toplu taşıma araçlarında tercih edilmesi, hem ekonomik hem de çevresel açıdan fayda sağlayacak bir dönüşüm olarak değerlendirilmektedir.

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SOĞUK ŞEKİLLENDİRME İŞLEMLERİ İÇİN ÇOK KATMANLI TRİBOLOJİK DLC KAPLAMA SİSTEMLERİNİN GELİŞTİRİLMESİ

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ÖZET

Günümüzde Diamond-Like Carbon (DLC) kaplamalar, düşük sürtünme katsayısı, yüksek aşınma direnci ve kimyasal stabilite gibi üstün nitelikleri sayesinde, çeşitli endüstriyel uygulamalarda yaygın olarak tercih edilen yüzey kaplama teknolojilerinden biri olmuştur.

Bu çalışmada, soğuk şekillendirme süreçlerinde özellikle delme gibi aşındırıcı koşullara maruz kalan kalıp elemanlarından biri olan zımbaların performansını artırmaya yönelik olarak, farklı alt katmanlarla desteklenmiş DLC esaslı kaplamaların tribolojik performansları kapsamlı bir şekilde değerlendirilmiştir. Bu doğrultuda, TiCN+DLC (Titanyum Karbo Nitrür + DLC), CrN+DLC (Krom Nitrür + DLC) ve Arc-DLC (Krom bazlı DLC) olmak üzere üç farklı çok katmanlı kaplama sistemi karşılaştırmalı olarak incelenmiştir.

Deneysel çalışmalar kapsamında; preslemedeki basım adedinin belirlenmesi, tribolojik performans analizleri ve aşınma testleri gerçekleştirilmiştir. Kaplamaların $100Cr_6$ çeliği ve Si_3N_4 (silisyum nitrür) karşı yüzeyleriyle olan etkileşimleri değerlendirilerek, sürtünme katsayıları (CoF) belirlenmiş; aşınma davranışları ve yüzeyde oluşan hasar türleri taramalı elektron mikroskobu (SEM) ile detaylı biçimde analiz edilmiştir. Tribolojik testlerden elde edilen sürtünme katsayısı verileri karşılaştırılmış, aşınma testlerinde ise numune yüzeylerinde meydana gelen malzeme kaybı, mikro çizikler, karşı yüzeyden malzeme transferi ve oksidasyon gibi hasar mekanizmaları tespit edilmiştir. Ayrıca, kaplamaların alt tabakaya yapışma dayanımı ve deformasyona karşı gösterdiği mekanik direnç değerlendirilmiştir.

Elde edilen bulgular, Arc-DLC kaplamasının diğer kaplama sistemlerine kıyasla daha düşük sürtünme katsayısı ve daha yüksek aşınma direnci sunduğunu ortaya koymuştur. Aşınma testlerinde bazı kaplama sistemlerinin yüzeylerinde daha az malzeme kaybı gözlenmiş; bazı

örneklerde yetersiz yapışma nedeniyle delaminasyon oluştuğu belirlenmiştir. Belirtilen sonuçlar doğrultusunda, bu tür çok katmanlı kaplamaların endüstriyel uygulamalarda daha dayanıklı hale getirilebilmesi için biriktirme tekniğinin, biriktirme parametrelerinin ve alt tabaka hazırlık koşullarının optimize edilmesinin gerekli olduğu tespit edilmiştir.

Anahtar Kelimeler: DLC Kaplama, Çok Katmanlı Kaplama, Tribolojik Performans, Aşınma Direnci, Sürtünme Katsayısı

DEVELOPMENT OF MULTILAYER TRIBOLOGICAL DLC COATING SYSTEMS FOR COLD STAMPING PROCESSES

ABSTRACT

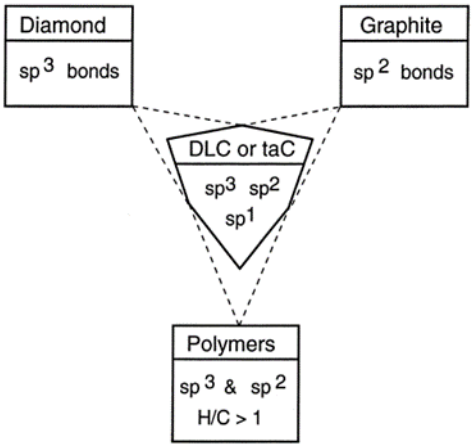
Nowadays, Diamond-Like Carbon (DLC) coatings have become one of the most widely adopted surface coating technologies in various industrial applications due to their superior properties such as low coefficient of friction, high wear resistance, and chemical stability.

In this study, the tribological performance of DLC-based multilayer coatings, reinforced with different interlayers, was comprehensively evaluated to enhance the functionality of punches—key die components that operate under abrasive conditions such as punching in cold forming processes. Accordingly, three different coating systems were comparatively investigated: TiCN+DLC (Titanium Carbonitride + DLC), CrN+DLC (Chromium Nitride + DLC), and Arc-DLC (Chromium-based DLC). The experimental procedures included determining the strokes during the press operation, performing tribological performance analyses and wear testing. The interaction of the coatings with counter surfaces made of $100Cr_6$ steel and Si_3N_4 (silicon nitride) was assessed, and their coefficients of friction (CoF) were determined. Wear behavior and surface damage types were analyzed in detail using scanning electron microscopy (SEM). The CoF values obtained from the tribological tests were compared, and in the wear tests, various damage mechanisms such as material loss, micro-scratches, material transfer from the counter surface, and oxidation were identified. Furthermore, the adhesion strength of the coatings to the substrate and their resistance to deformation were evaluated. The results demonstrated that the Arc-DLC coating exhibited a lower coefficient of friction and higher wear resistance compared to the other coating systems. In some cases, less material loss was observed on the coated surfaces during wear tests. However, it has been revealed that certain coatings exhibited delamination due to insufficient adhesion to the substrate. Based on these findings, it was concluded that to enhance the durability of such multilayer coatings in industrial applications, the deposition parameters and substrate preparation conditions must be optimized.

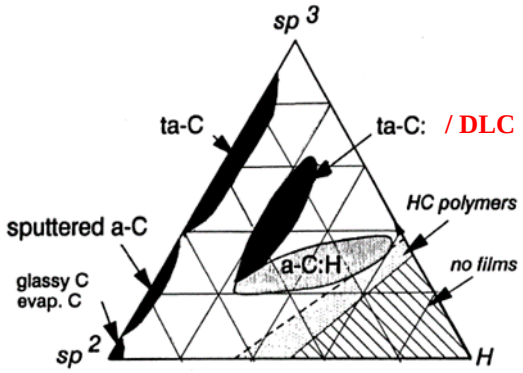
Keywords: DLC Coating, Multilayer Coating, Tribological Performance, Wear Resistance, Friction Coefficient

GİRİŞ

Elmas Benzeri Karbon (Diamond-Like Carbon, DLC) kaplamalar, düşük sürtünme katsayısı, yüksek sertlik, yüksek aşınma direnci, kimyasal kararlılık, yüksek termal iletkenlik, yüksek elektriksel direnç ve düşük termal genleşme gibi üstün tribolojik ve kimyasal özellikleri sayesinde; otomotiv, kalıpçılık ve biyomedikal gibi çok çeşitli endüstriyel uygulamalarda yaygın olarak tercih edilen yüzey kaplama teknolojilerinden biri haline gelmiştir (Donnet ve Erdemir, 2008; Robertson, 2002; Grill, 1999). DLC kaplamaların bu denli geniş bir kullanım alanına sahip olmasında, karbonun farklı hibritleşme durumlarının (sp^1, sp^2 ve sp^3) (Şekil 1) bulunması ve bu yapıların fiziksel özellikler üzerindeki belirleyici rolü etkili olmaktadır (Robertson, 2002).

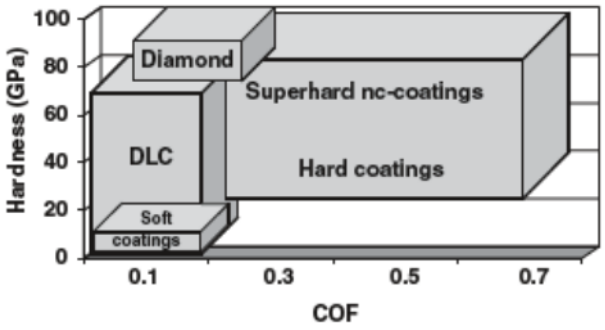


Şekil 1. DLC kaplamanın farklı hibritleşme durumları (Koidl ve ark., 1991)



Şekil 2. DLC kaplamaların faz diyagramı (Robertson, 1997)

Ayrıca, düşük sürtünme katsayısı ile enerji kayıplarını azaltması ve yüksek aşınma direnci ile takım ömrünü uzatması gibi avantajları, mühendislik uygulamalarında özellikle kaplama performansının kritik olduğu alanlarda DLC kaplamayı vazgeçilmez kılmaktadır (Erdemir ve Donnet, 2006). Şekil 3'te, kaplamaların sertlik ve sürtünme katsayısı (CoF) ilişkisi görülmektedir. DLC kaplamalar, yüksek sertlik ve düşük CoF değerleriyle ön plana çıkmaktadır. Bu özellikleri sayesinde, aşınmaya karşı direnç sağlamakta ve elmas kaplamalara benzer performans sunarken aynı zamanda daha ekonomik bir alternatif oluşturmaktadırlar (Erdemir ve Donnet, 2006).



Şekil 3. Karbon bazlı kaplamalar ve diğer kaplamaların sertlik ve sürtünme katsayısının (CoF) şematik gösterimi (Donnet ve Erdemir, 2008)

Deneysel çalışmalar, kaplamaların performansını değerlendirmede önemli bir rol oynamaktadır. Sürtünme ve aşınma testleri, şekillendirme ve kesme/delme işlemleri sırasında takım ömrü ve operasyonel verimlilik üzerindeki etkileri açısından kaplamaları değerlendirmek için gerçekleştirilen başlıca testlerdendir. Özellikle, kaplamaların seri üretimdeki basım adedinin belirlenmesini, farklı kaplama sistemlerinin aşınma oranı ve sürtünme üzerindeki etkilerinin karşılaştırıldığı tribolojik performans analizlerini kapsamaktadır. Bu değerlendirmeler, çeşitli kaplama yapılarının zorlu koşullar altında davranışlarını göstermektedir (Kawaguchi ve ark., 2008; Ling ve ark., 2012).

Bu çalışmada, soğuk şekillendirme uygulamalarında, özellikle delme gibi yüksek aşınma riski taşıyan işlemlerde kullanılan kalıp bileşenlerinden zımbaların dayanımını artırmak amacıyla, farklı alt tabaka kombinasyonlarıyla desteklenen DLC bazlı kaplamaların tribolojik özellikleri detaylı şekilde incelenmiştir. Bu kapsamda, TiCN+DLC (Titanyum Karbo Nitrür + DLC), CrN+DLC (Krom Nitrür + DLC) ve Arc-DLC (Krom bazlı DLC) olmak üzere üç farklı çok katmanlı kaplama yapısı karşılaştırmalı olarak değerlendirilmiştir.

GELİŞME

Malzeme ve Metot

Bu çalışma kapsamında, salıncak kolu (Şekil 4) üretiminde kullanılan sıvama zımbaları üzerine farklı çok katmanlı kaplama sistemleri uygulanmış, kaplamaların tribolojik performanslarının değerlendirilmesi ve seri üretimde basım adedinin tayin edilmesi amaçlanmıştır. Bu parçanın seçilmesinin nedeni, şaşi ürünlerinin yüksek parça kalınlıkları nedeniyle dakikadaki pres vuruş sayısında (SPM) istenilen seviyelere ulaşılamamasıdır. Yüksek kalınlıklara sahip şaşi parçalarında SPM'in artırılması sonucunda; kalıp elemanlarının ısınması ve zımba üzerindeki kaplamanın önemli ölçüde aşınması gibi parça yüzeyinde istenmeyen görsel ve boyutsal hatalar meydana gelmektedir.

Şekil 4. Salıncak kolu

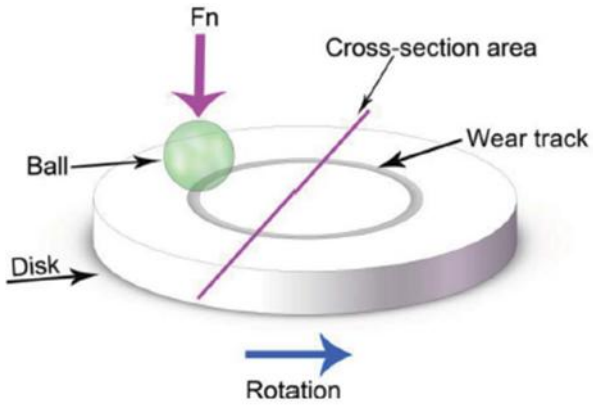
Deneysel çalışmalarda kullanılan zımbalar, TiCN + DLC, CrN + DLC ve Arc-DLC olmak üzere farklı kaplama sistemleriyle kaplanmıştır. TiCN + DLC ve CrN + DLC kaplamaları, (a-C:H:Me) magnetron püskürtme yöntemiyle, Arc-DLC kaplaması ise katodik ark yöntemiyle zımba yüzeyine uygulanmıştır (Şekil 5).

Şekil 5. DLC kaplanmış zımbalar

Uygulamada kullanılan salıncak kolu malzemesi, 4 mm kalınlığında ve CPW 800 kalite sınıfındadır. Kaplamalar 574 × 174 × 20 mm³ boyutlarındaki hedef malzeme (target) kullanılarak gerçekleştirilmiş olup, kaplama kalınlıkları 2,5–3 µm aralığında değişmektedir. Kaplamaların yaklaşık sertliği 2200 HV ve maksimum servis sıcaklıkları 200 °C'dir. Karakterizasyon çalışmaları kapsamında kaplamaların mikroyapısal özellikleri taramalı elektron mikroskobu (SEM) ve optik (konfokal) mikroskop kullanılarak incelenmiş olup, tribolojik özellikleri ise ball-on-disk testi ile değerlendirilmiştir. Ayrıca, seri üretim sırasında zımbaların ömrü, basım adedi tayini ile takip edilmiş ve kaplama bütünlüğü değerlendirilmiştir. Elde edilen tüm bu veriler, farklı kaplama sistemlerinin zımbalar üzerindeki performansını hem yapısal hem de işlevsel açıdan karşılaştırmalı olarak değerlendirmek amacıyla kullanılmıştır.

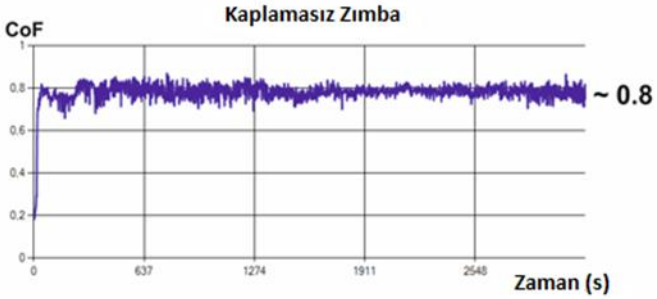
SONUÇLAR

Çalışma kapsamında, farklı kaplama kombinasyonlarına sahip sıvama zımbalarının sürtünme katsayısı (CoF) değerleri, ball-on-disk (Şekil 6) tribolojik test yöntemi kullanılarak belirlenmiştir. Elde edilen sonuçlar ile kaplamaların tribolojik performansları karşılaştırmalı olarak değerlendirilmiştir.



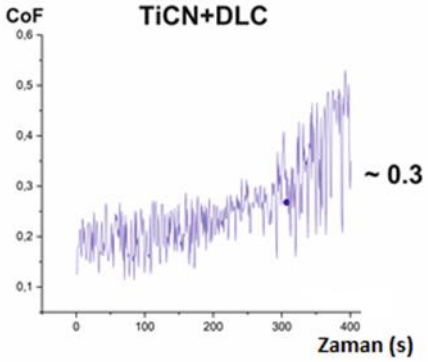
Şekil 6. Ball-on disk tribolojik test düzeneği şematik gösterimi (Xu ve ark., 2015)

Kaplamasız numunede sürtünme katsayısı yaklaşık 0.8 olarak ölçülmüştür (Şekil 7). Bu değer, oldukça yüksek olup yüzeyde herhangi bir kaplamanın bulunmamasının temas bölgesinde yüksek sürtünmeye yol açtığını göstermektedir. Elde edilen bu bulgu, kaplamaların, yüzeyi iyileştirerek tribolojik performansını önemli ölçüde artırdığını ortaya koymaktadır.



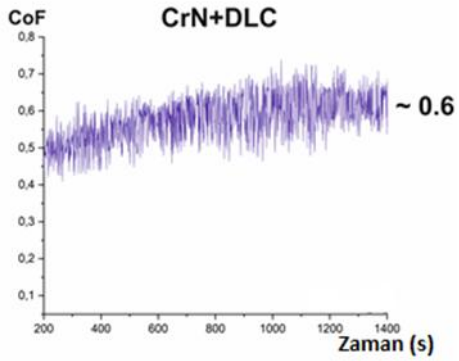
Şekil 7. Kaplamasız sıvama zımbasının zamana bağlı sürtünme katsayısı grafiği

TiCN+DLC kaplamalı numune için sürtünme katsayısı değeri yaklaşık 0.3 seviyelerinde seyretmiştir (Şekil 8). Bu durum, kaplamalı yüzeyin kaplamasız yüzeye kıyasla önemli ölçüde iyileşme sağladığını göstermektedir. Ancak test süresinin ilerlemesiyle birlikte CoF değerinde artış gözlenmiş; bu durum, kaplama yüzeyinin zamanla aşınmaya başladığını veya kaplamanın yapısal bütünlüğünün uzun süreli yüklemeler altında tam olarak korunamadığını ortaya koymaktadır.



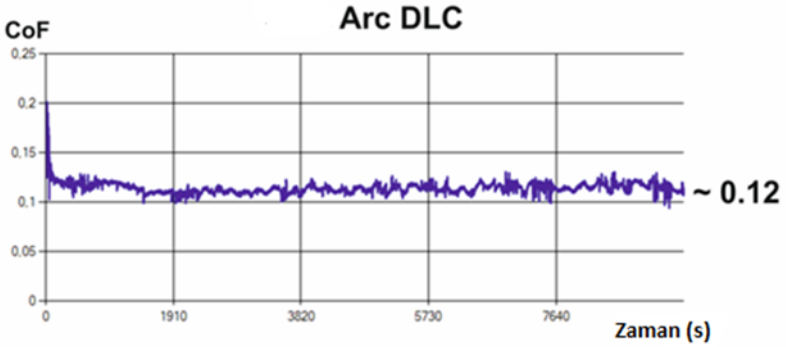
Şekil 8. TiCN + DLC sıvama zımbasının zamana bağlı sürtünme katsayısı grafiği

CrN+DLC kaplamalı numunede ise sürtünme katsayısı yaklaşık 0.6 olarak ölçülmüştür (Şekil 9). Bu değer, TiCN+DLC kaplamaya kıyasla daha yüksek olup, kaplama malzemesi kombinasyonunun sürtünme direncinde yeterli performansı gösteremediğini ortaya koymaktadır. Burada da zamanla artan CoF değeri, yüzeyin aşınmaya maruz kaldığını göstermektedir.



Şekil 9. CrN + DLC sıvama zımbasının zamana bağlı sürtünme katsayısı grafiği

Ball-on disk tribolojik testler sonucunda elde edilen zamana bağlı sürtünme katsayısı değerlerine kıyasla en iyi performans Arc-DLC kaplamalı numunede elde edilmiştir (Şekil 10). Bu numunede sürtünme katsayısı test süresi boyunca oldukça düşük seviyelerde kararlı şekilde sabit kalmış ve yaklaşık 0.12 olarak ölçülmüştür (Şekil 10). Bu sonuç, Arc DLC kaplamanın yüksek aşınma direnci ve düşük sürtünme özelliklerine sahip olduğunu, dolayısıyla tribolojik performans açısından alternatiflerine kıyasla en uygun seçenek olduğunu göstermektedir. Grafikte gözlemlenen düşük dalgalanma kaplamanın kararlılığını desteklemektedir.

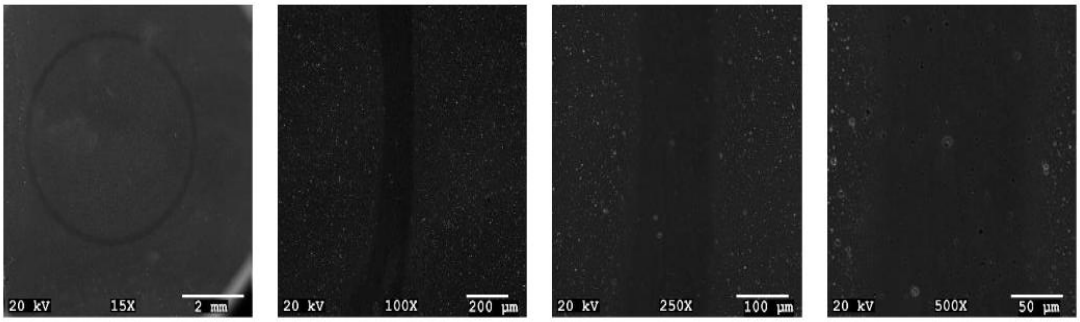


Şekil 10. Arc DLC sıvama zımbasının zamana bağlı sürtünme katsayısı grafiği

Yapılan tribolojik testler sonucunda DLC bazlı kaplamaların sürtünme katsayısı ve aşınma direnci açısından kaplamasız yüzeylere kıyasla oldukça üstün performans gösterdiği ortaya konmuştur. Özellikle Arc-DLC kaplama, diğer kaplama türlerine kıyasla en düşük sürtünme katsayısını sağlayarak yüksek bir tribolojik dayanım göstermiştir.

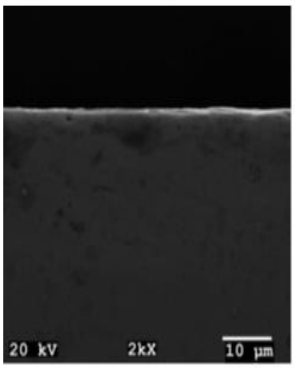
Bu testin ardından özellikle tribolojik performansı en yüksek olan Arc-DLC kaplama özelinde yapılan yüzey karakterizasyonu çalışmaları ile kaplamanın aşınma davranışı daha ayrıntılı şekilde değerlendirilmiştir. Arc-DLC kaplamalarda, farklı büyütmelerde elde edilen taramalı elektron mikroskobu (SEM) görüntülerinde (2 mm, 200 µm, 100 µm, 50 µm ölçekte), kaplama üzerinde oluşan aşınma izinin sınırlı olduğu ve yüzeyin büyük ölçüde bütünlüğünü koruduğu görülmektedir (Şekil 11). Ancak, özellikle mikrometre ölçekli görüntülerde küçük ölçekte

deliminasyonlar tespit edilmiştir. Bu deliminasyonlara rağmen kaplamanın test süresince aşınmaya karşı yüksek direnç gösterdiği ortaya konmuştur.



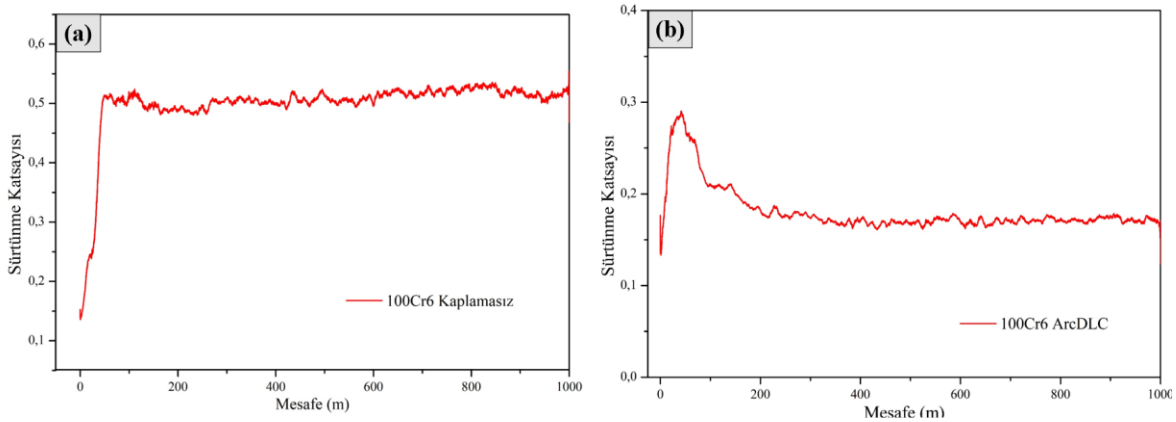
Şekil 11. Arc-DLC kaplama aşınma izi (2 mm, 200 µm, 100 µm, 50 µm)

Ayrıca, Arc-DLC kaplamanın Şekil 12'deki kesit görüntüsü, kaplama kalınlığının homojen bir dağılım gösterdiğini ortaya koymaktadır. Katmanlar arasında belirgin bir ayrımın olmaması ve yapısal süreklilik, kaplama dayanımını destekleyici önemli unsurlardandır.



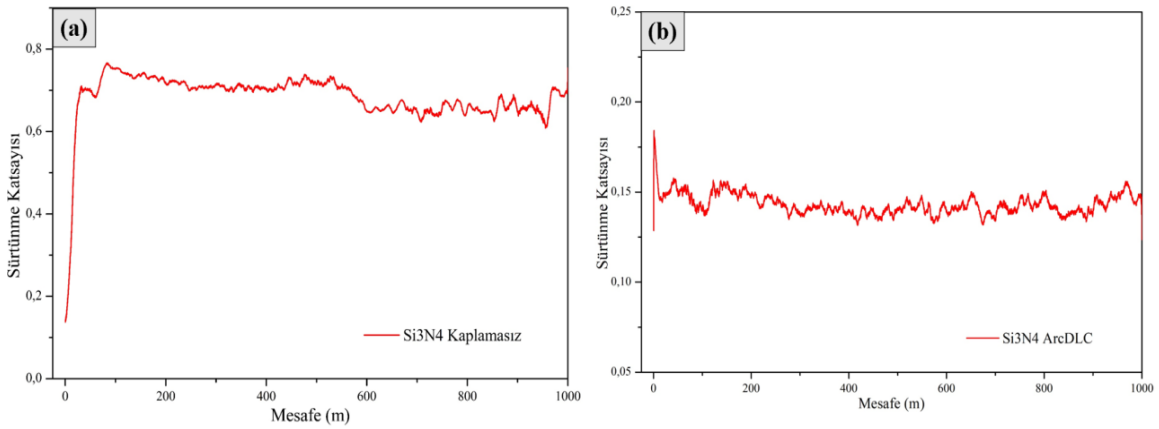
Şekil 12. Arc-DLC kaplama kaplama bölgesi (10 µm)

Şekil 13 ve Şekil 14'te yer alan grafikler, kaplamasız ve kaplamalı Arc-DLC zımbanın 100Cr6 ve Si_3N_4 karşıt yüzeyleriyle yapılan sürtünme testlerinden elde edilen sürtünme katsayısı (CoF) değişimlerini göstermektedir. Bu grafikler, malzeme çiftlerinin tribolojik davranışlarını karşılaştırmalı olarak değerlendirmek açısından önemli veriler sunmaktadır.
Şekil 13'te, kaplamasız alt tabakanın (a) ve Arc-DLC kaplı yüzeyin (b), 100Cr6 yüzeye karşı sürtünme davranışı incelenmiştir. Kaplamasız numunede sürtünme katsayısının hızla yükselerek sabit bir değerde (~0,5) seyrettiği gözlemlenmiştir. Buna karşılık, Arc-DLC kaplı yüzeyde sürtünme katsayısı düşük seviyelerde (~0,15) ve daha stabil bir şekilde seyretmektedir. Bu sonuç, Arc-DLC kaplamanın 100Cr6 yüzeye karşı sürtünmeyi önemli ölçüde azalttığını ve daha kararlı bir yapı sağladığını göstermektedir.



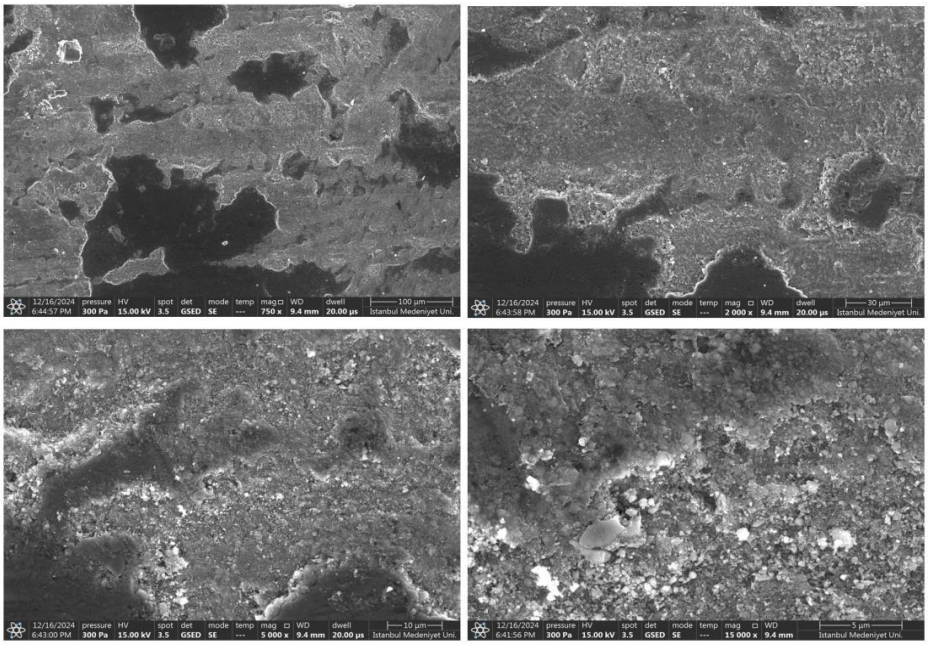
Şekil 13. Kayma mesafesine göre Sürtünme Katsayısı (CoF); (a) kaplamasız alt tabaka ve (b) Arc – DLC kaplamaya karşı 100Cr6 karşıt yüzey (bilye)

Şekil 14'te ise benzer karşılaştırma Si_3N_4 karşıt yüzey ile yapılmıştır. Kaplamasız yüzeyin (a) daha yüksek (~0,7) ve dalgalı bir sürtünme davranışı sergilediği görülürken, Arc-DLC kaplı yüzeyin (b) sürtünme katsayısı düşük seviyelerde (~0,15) sabitlenmiş ve daha kararlı bir sürtünme profili elde edilmiştir. Her iki grafik birlikte değerlendirildiğinde ise, Arc-DLC kaplamanın hem metal (100Cr6) hem de seramik (Si_3N_4) karşıt yüzeylere karşı düşük sürtünme ve daha stabil temas koşulları sunduğu net şekilde anlaşılmaktadır. Bu da Arc-DLC kaplamanın geniş bir uygulama yelpazesinde tribolojik avantaj sağladığını göstermektedir.



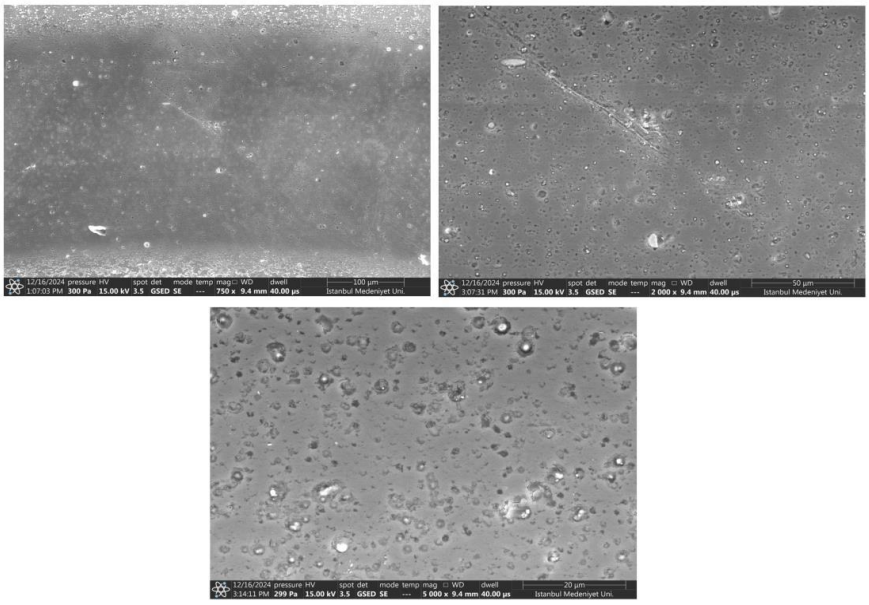
Şekil 14. Kayma mesafesine göre Sürtünme Katsayısı (CoF); (a) kaplamasız alt tabaka ve (b) Arc – DLC kaplamaya karşıt Si_3N_4 karşı yüzey (bilye)

Bir diğer analiz sonucu da Şekil 15'te görülmektedir. 100Cr6 karşıt yüzeyle temas eden kaplanmamış alt tabakanın yüzeyinde ciddi düzeyde plastik deformasyon, malzeme yığılması ve belirgin yapışma aşınması izleri SEM analizleri ile tespit edilmiştir. Aşınmış yüzeyler üzerinde düzensiz oyuklar, yırtılmalar ve birikmiş partiküller gözlemlenmiştir. Bu durum, alt tabakanın karşı yüzeyle sürtünmesi sırasında yüksek yüzey hasarı aldığını ve yüzeyin mekanik olarak zayıf kaldığını göstermektedir. Özellikle mikroyapısal bozulmalar, kaplama yapılmamış yüzeyin yük taşıma kapasitesinin düşük olduğu bilgisini desteklemektedir.



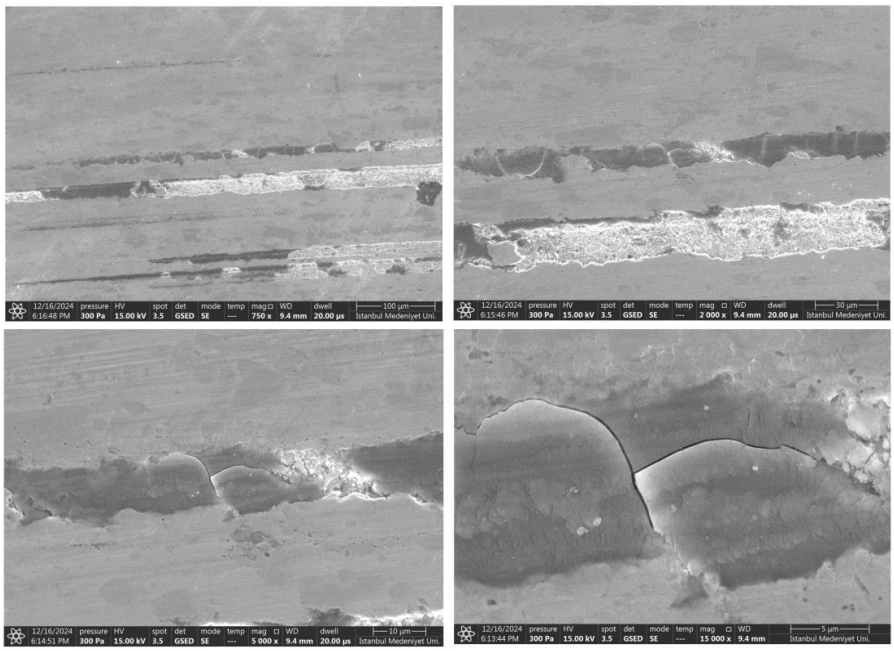
Şekil 15. 100Cr6 karşıt yüzeye karşı kaplamasız alt tabakanın aşınmış yüzeylerini gösteren SEM görüntüleri

Buna karşın, Şekil 16'da gösterilen, Arc-DLC kaplamalı yüzeylerin 100Cr6 karşıt yüzeyle teması sonrasında oldukça düzgün ve homojen bir aşınma yüzeyi oluşturduğu gözlemlenmiştir. Yüzeyde belirgin bir plastik deformasyon veya malzeme transferi görülmemektedir. Sadece yüzeye dağılmış küçük boyutlu aşınma izleri ve mikro çukurcuklar yer almaktadır. Bu da Arc-DLC kaplamanın yüzeyinin nispeten başarılı bir şekilde korunduğunu ancak yapışma aşınması performansının iyileştirilmesi gerektiğini ortaya koymaktadır.



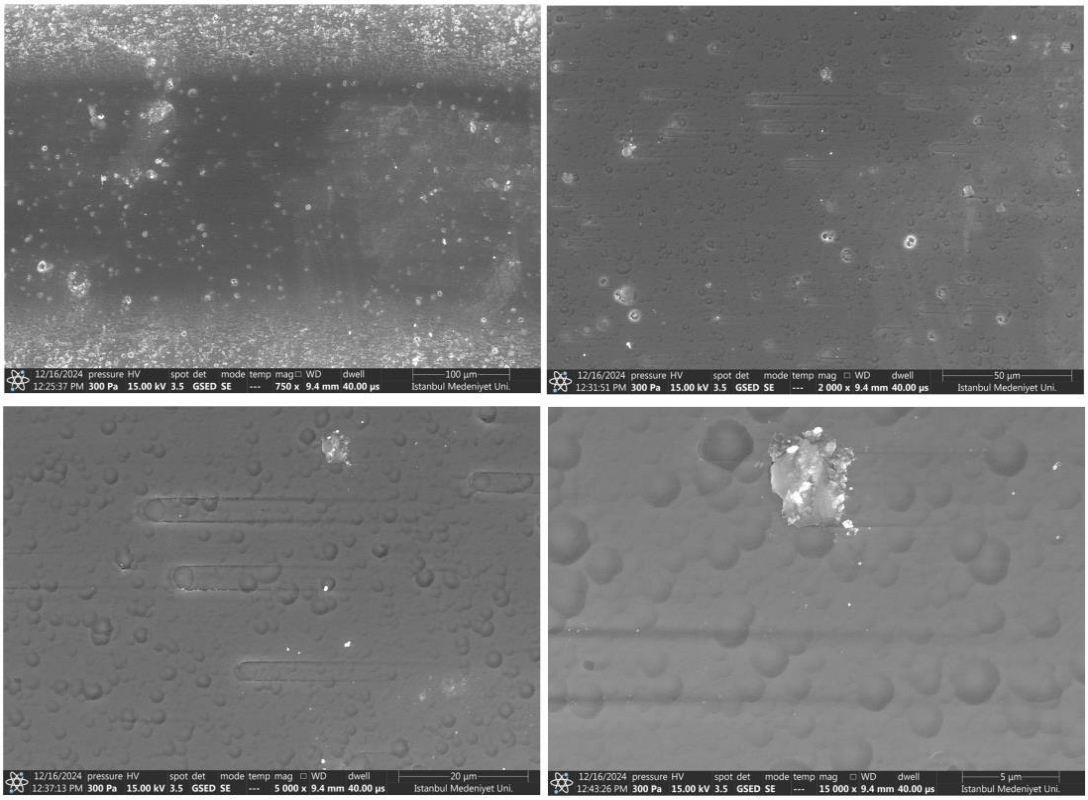
Şekil 16. 100Cr6 karşıt yüzeye karşı Arc-DLC kaplamanın aşınmış yüzeylerini gösteren SEM görüntüleri

Benzer şekilde, Si_3N_4 karşıt yüzeyle gerçekleştirilen aşınma testlerine ait SEM analizleri de kaplamasız alt tabaka ile Arc-DLC kaplı numuneler arasında gözle görülür farklar ortaya koymuştur. Şekil 17'de gösterilen kaplanmamış alt tabaka yüzeylerinde, Si_3N_4 karşıt yüzeye karşı gerçekleşen temas sonrasında belirgin çizikler, çatlaklar ve yer yer malzeme kopmaları tespit edilmiştir. Bu aşınma izleri, karşıt yüzeye karşı kaplamasız numunenin ciddi bir mekanik zorlanmaya maruz kaldığını ve yüzeyin yapısal bütünlüğünün bozulduğunu göstermektedir. Yüzeyin, temas bölgelerinde lokal plastik deformasyona uğradığı ve bu durumun çatlak ilerlemesine zemin hazırladığı görülmektedir.



Şekil 17. Si_3N_4 karşıt yüzeye karşı kaplamasız alt tabakanın aşınmış yüzeylerini gösteren SEM görüntüleri

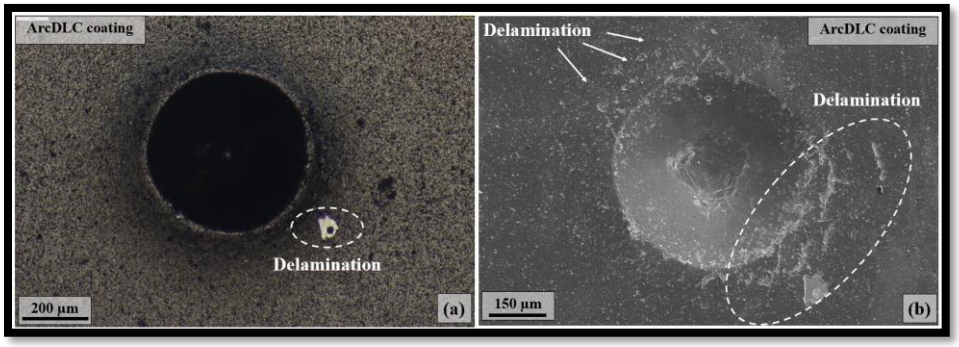
Buna karşın, Şekil 18'de yer alan Arc-DLC kaplamalı yüzeyler, Si_3N_4 karşıt yüzeye karşı oldukça düzgün, minimal hasar içeren bir aşınma yüzeyi sunmaktadır. Yüzeyde dağınık halde mikroskobik düzeyde aşınma çukurcukları ve yüzeye yapışmış bazı partiküller dışında belirgin bir çizik, çatlak ya da ciddi deformasyon görülmemektedir.



Şekil 18. Si_3N_4 karşıt yüzeye karşı Arc-DLC kaplamanın aşınmış yüzeylerini gösteren SEM görüntüleri

Akabinde Şekil 19'da yer alan optik (a) ve taramalı elektron mikroskobu SEM (b) mikrograf analizleri, kaplamalı Arc-DLC zımbanın yüzeyinde oluşan hasarları ve delaminasyon (kaplamanın yüzeyden ayrılması) bölgelerini ayrıntılı şekilde incelemek adına gerçekleştirilmiştir. Bu mikroskobik incelemeler, tribolojik testler sonrasında kaplamada meydana gelen yapısal bozulmaların ayrıntılı şekilde incelenmesini mümkün kılmaktadır.

Optik mikrografta (Şekil 19a), aşınma sonrası yüzeyde belirgin bir dairesel aşınma izi gözlemlenmiş ve bu bölgenin çevresinde küçük ölçekte delaminasyon alanları tespit edilmiştir. Bu alanlarda, kaplamanın alt tabakadan ayrıldığı açıkça görülmektedir. Bu durum, kaplama ile alt yüzey arasındaki yüzeye yapışma kalitesinin bazı bölgelerde yetersiz kaldığını göstermektedir. SEM görüntüsü (Şekil 19b) ise bu durumu daha net bir şekilde ortaya koymaktadır. Yüzeyde yaygın mikro çatlaklar ve parçalanmalarla birlikte, delaminasyon izleri görülmektedir. Mikrograf üzerinde işaretlenen bölgeler, kaplamanın bazı yerlerde soyulduğunu veya ayrıldığını göstermektedir. Belirtilen sonuçlar doğrultusunda, bu tür çok katmanlı kaplamaların endüstriyel uygulamalarda özellikle yüzeye yapışma açısından daha dayanıklı hale getirebilmek için biriktirme tekniği, biriktirme parametreleri ve alt tabaka hazırlık koşullarının optimize edilmesinin gerekliliği ortaya konmuştur.



Şekil 19. Arc-DLC kaplamanın (a) optik ve (b) SEM mikrografları

Seri üretim koşullarında gerçekleştirilen denemeler sonucunda ise; aşınma performansını sayısal olarak ifade eden bir gösterge olan basım adedi verilerine göre, CrN+DLC kaplaması yalnızca 130 basımda aşınmaya uğrarken, TiCN+DLC kaplaması 2430 basıma, Arc-DLC kaplaması ise 15.001 basıma kadar dayanım göstermiştir (Tablo 1). Bu veriler, Arc-DLC kaplamanın rakiplerine kıyasla yaklaşık 6 kat daha yüksek performans gösterdiğini ortaya koymakta ve bu sonucu desteklemektedir. Ayrıca basım adedi sonuçları, ölçülen CoF değerleri ile orantılı bir performans sergilemiştir.

Tablo 1. DLC Kaplamaların Basım Adedi Bazında Karşılaştırılması

KAPLAMA TÜRLERİ	***BASIM ADEDİ***
CrN +DLC	**130**
TiCN +DLC	**2430**
ARC DLC	**15001**

Yapılan test ve analizler sonucunda, Arc-DLC kaplamanın, incelenen diğer kaplama türlerine kıyasla düşük sürtünme katsayısı ve yüksek aşınma direnci ile özellikle soğuk şekillendirmede zorlu yüzey temaslarının yaşandığı uygulamalarda önemli avantajlar sunduğu ortaya konmuştur. Hem metalik (100Cr6) hem de seramik (Si_3N_4) karşıt yüzeylerle gerçekleştirilen testlerde, Arc-DLC kaplamanın, aşınma davranışını belirgin şekilde iyileştirdiği ve kaplanmamış alt tabakalara kıyasla oldukça az yüzey hasarı oluşturduğu tespit edilmiştir. Bu doğrultuda, Arc-DLC kaplamalar, mevcut çalışma kapsamında değerlendirilen TiCN+DLC ve CrN+DLC kaplamalarına kıyasla, takım ömrünü uzatarak üretim verimliliğini artırma potansiyeliyle öne çıkmakta ve endüstriyel uygulamalar için güçlü bir kaplama çözümü sunmaktadır. Tüm bunların yanı sıra, Arc-DLC kaplamanın, uzun süreli ve yüksek yük altında çalışan uygulamalarda kaplamanın yapışma kalitesinde bazı sorunların gözlenmesi, endüstriyel kullanımda kaplamanın daha kararlı hale getirilebilmesi için yüzey hazırlık süreçlerinin, biriktirme tekniğinin ve biriktirme parametrelerinin iyileştirilmesinin gerekli olduğu gözlemlenmiştir. Yapılan iyileştirmelerin akabinde daha yüksek basım adetlerine ulaşılacağı öngörülmektedir.

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DRİVERS AND ENVİRONMENTAL IMPACTS OF DEFORESTATİON İN EASTERN EUROPE: A LİTERATURE REVİEW

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ABSTRACT
Deforestation is one of the key environmental concerns in Eastern Europe, which is driven by tensions of economic, political, and social pressures. This literature review identifies the central causes of deforestation in the region, ranging from illegal logging to agricultural expansion, infrastructure development, and ineffective forest conservation policy. Romania and Ukraine are significantly affected by deforestation due to wood demand, urbanization, and agricultural land use change. The review also establishes the severe environmental impacts of deforestation such as changes in local climate patterns, disruptions to the water cycle, erosion, and loss of biodiversity. The paper presents further responses to deforestation on national and international scales such as conservation, policy responses, and the role of NGOs and satellite tracking in reacting to illegal deforestation. Despite existing efforts, a major issue remains to address the long-term conservation of forests and sustainable land use in Eastern Europe. The paper concludes with a call to impose stronger action, more international cooperation, and better conservation measures to mitigate the environmental effects of deforestation in the region.
Keywords: Deforestation, Climate Change, Environmental Impact, Eastern Europe, Biodiversity, Soil Degradation, Forest Conservation, Environmental Policies, Romanie, Ukraine

INTRODUCTION

Ecosystems of Eastern European forests serve as a vital function in the environment: they occupy approximately 40% of the surface and supply necessary services to the ecosystem (European Environment Agency, 2022). The Carpathian forests, for example, sustain Europe's largest populations of carnivores (bears, wolves, and lynxes) and threatened populations of birds (UNEP, 2023). Forests have been under a series of pressures since the second half of the 20th century. While the forest cover in the area expanded somewhat from 1985 to 2012, a great deal of wood harvesting, such as illegal logging, continues to be a leading driver of forest loss (Taff et al., 2013; Potapov et al., 2015). Forest degradation caused by agriculture, insect problems, and climatic conditions also adds to ecosystem fragmentation and the loss of many species.

These drivers have imposed significant ecological costs and governance challenges (e.g., persistent illegal logging); policy responses include EU measures (e.g., the Timber Regulation) to curb unsustainable practices. Against this backdrop, this literature review addresses the question: *"What are the primary environmental drivers of deforestation in Eastern Europe, and how have these contributed to ecological degradation and policy challenges in the region?"* The review is organized into three sections examining (1) *Drivers of Deforestation in Eastern Europe*; (2) *Ecological Impacts of Forest Loss*; and (3) *Policy Responses and Governance Challenges*.

RESEARCH AND FINDINGS

Drivers of Deforestation in Eastern Europe

Scholars identify several recurring drivers of deforestation in Eastern Europe: post-socialist land reforms, illegal logging under weak governance, persistent historical land-use legacies, and emerging climate stresses. For example, Griffiths et al. (2012) and Alix-Garcia et al. (2016) note that many Carpathian forests were restituted to private owners after the fall of socialism, and that this surge in private ownership and access to EU timber markets "contributed to high logging rates." Similarly, Knorn et al. (2013) observe that forest disturbance rates remained low around 1990 but then rose sharply in waves after 1995 and 2005, attributing this to rapid ownership and institutional changes associated with land reforms. These findings suggest that the post-1990 transition – involving restitution, privatization, and the dismantling of state forest institutions – is a central driver of recent forest loss (Griffiths et al., 2012; Knorn et al., 2013).

Illegal logging, often linked to poverty and governance gaps, is widely cited as a second major driver. Bouriaud (2005) finds that illegal harvesting is strongly tied to poverty, land reform, and weak law enforcement. Governance gaps facilitate illicit harvesting: officials often turn a blind eye to unlicensed cutting in exchange for bribes. Despite some stabilization since the 1990s, corruption and unclear tenure mean that illegal logging remains widespread in Eastern Europe.

Long-term land-use history also shapes deforestation patterns. Alix-Garcia et al. (2016) emphasize that "past land uses can greatly affect subsequent forest disturbance." In practice, landscapes with legacies of agriculture or early industrial forestry have higher deforestation rates, whereas areas with a history of continuous forest cover are comparatively resistant. Thus, historical land-use legacies condition current forest loss, a point underscored by several authors.

Finally, climate change is emerging as an indirect driver of forest loss. Shvidenko et al. (2017) note that warming has already brought "hotter droughts of historically unprecedented severity," intensifying tree mortality and disturbances. Knutzen et al. (2025) likewise document recent heatwaves and droughts causing widespread die-off in Europe and underscore that "tailored strategies are essential to mitigate climate change impacts" on forests. In sum, climate-induced stressors (drought, pests, fire) now compound anthropogenic pressures on Eastern European forests, making climate change an increasingly significant factor in deforestation.

Ecological Impacts of Forest Loss

Deforestation in Eastern Europe – driven largely by post-socialist land reform and intensive logging – has incurred serious ecological costs. Multiple studies document steep declines in biodiversity as contiguous woodlands are cut down. In the Romanian Carpathians, for example, *old-growth* forests that harbor rare flora and fauna shrank by approximately 1.3% between 2000 and 2010, despite the expansion of protected areas. Notably, over 70% of these disturbances occurred *inside* reserves, reflecting weak enforcement amid the legal restitution of private forest lands. Such fragmentation isolates wildlife populations and disrupts migration corridors (Knorn *et al.*, 2013; Griffiths *et al.*, 2012). Researchers emphasize that Eastern Europe's remnant virgin forests are biodiversity hotspots; logging and conversion have exposed many specialist species to local extirpation (Knorn *et al.*, 2013). In Ukraine, climate-driven stress compounds these losses: projections suggest that half the country may become too warm and dry to support the current tree species, effectively 'impoverishing' forest ecosystems (Shvidenko *et al.*, 2017) and threatening species with narrow climatic tolerances.

Forest loss also critically undermines ecosystem services. Eastern Europe's forests are major carbon sinks and regulators of water and soil stability. Shvidenko *et al.* (2017) estimate that Ukraine's forests sequester approximately 11 Tg C per year – among the highest per-area sinks in Europe – but warn that this will collapse under future warming. Likewise, the loss of tree cover sharply reduces flood mitigation and increases soil erosion. In Ukraine, only approximately 11% of the land remains in a "favorable" ecological condition, whereas over one-third of cropland suffers from water erosion and over half suffers from wind erosion. Romania's deforestation has similarly amplified landslides and sediment loads in mountain watersheds. Deforestation also weakens hydrological regulation, making streamflows more erratic and summer droughts more severe. In combination, these effects degrade agricultural soil and freshwater quality that was once sheltered by intact forests.

Increasing evidence shows that forest degradation heightens vulnerability to climate disturbances. Heat waves and droughts now cause unprecedented tree mortality in Europe (Knutzen *et al.*, 2025). For example, recent multi-year droughts severely impacted central European forests, even in otherwise resilient stands. Under warmer conditions, stress-weakened forests are more susceptible to pest and pathogen outbreaks. Shvidenko *et al.* (2017) note that Ukraine's increasing drought stress is already leading to massive insect and disease impacts: the area of forest damaged by pests and pathogens rose from approximately 4% in the 1990s to 8% by the 2010s, and wildfire area roughly doubled. They forecast that extreme drought, insect outbreaks, and fires will become increasingly common, especially in southern and eastern Ukraine. In sum, fragmented and degraded forests lose their buffering capacity against climate extremes, creating a feedback loop of disturbance.

Across studies, a recurring insight is that anthropogenic drivers – from poverty-driven illegal logging to market liberalization – exacerbate these impacts. Bouriaud (2005) documents how poverty and weak law enforcement in Eastern Europe (especially in Romania) fuel illegal harvests that fragment habitats and diminish stand structure. Alix-Garcia *et al.* (2016) similarly identify the post-socialist transition – private ownership and access to global timber markets – as a key catalyst of intense logging. These human pressures overlay regional distinctions: in Romania, the primary concern is continued logging inside parks and lack of governance (Knorn *et al.*, 2013; Bouriaud, 2005), whereas in Ukraine the interplay of deforestation, climate stress, and recent conflict has driven massive losses. In all cases, degraded forests translate into broad degradation of soil, carbon stores, and watershed health. The consensus of the literature is clear: Eastern Europe's ongoing loss of forest is leading to biodiversity decline and fragmentation, impaired ecosystem services (carbon sequestration, water, and soil protection), and greatly increased susceptibility to climate-driven disturbances (Alix-Garcia *et al.*, 2016; Knorn *et al.*, 2013; Shvidenko *et al.*, 2017; Bouriaud, 2005). Without stronger governance and restoration policies, these impacts threaten the region's environmental stability.

Policy Responses and Governance Challenges

Forests in Eastern Europe have been heavily shaped by post-socialist policy reforms. In Romania, successive forest restitution laws (1991, 2000, 2005) transferred much forestland back to private hands and were followed by sharp increases in logging disturbances. Griffiths et al. (2012) used Landsat time-series to show that forest disturbance in Romania jumped after each restitution law, amounting to 75,000 ha (4.5% of the study area) between 1989 and 2012. They note that private ownership and access to EU markets "contributed to high logging rates" in the Carpathians, raising fears of timber overexploitation. Alix-Garcia et al. (2016) similarly report that post-socialist privatization and land conversion (often to agriculture) intensified deforestation in the region. In practice, fragmented ownership and weak local control have undercut sustainable management. Even where forests were returned to community ownership, rigid, top-down planning regimes often left owners with little influence over harvesting. As a result, restitution has sometimes exacerbated degradation rather than restoring forests.

Protected areas have been expanded in response, but enforcement gaps remain. Knorn et al. (2013) document an *increasing* Natura 2000 and park network in Romania – yet they found continued loss of old-growth forest: 72% of old-growth disturbances occurred *within* protected areas. This paradox highlights weak governance: protected status alone did not shield forests because illegal or poorly regulated logging persisted. Bouriaud (2005) also notes that policy reforms left many countries with "unclear and unstable ownership rights" and law enforcement failures, creating incentives for illegal harvest. In short, while states have declared new protected forests, limited monitoring and corruption often render enforcement ineffective.

Illegal logging enforcement has generally been weak throughout Eastern Europe. Bouriaud's analysis finds that rural poverty, incomplete land reform, and weak law enforcement are major drivers of illegal logging. Many new private owners lack resources or knowledge to manage sustainably, while oversight agencies often remain underfunded. Attempts at institutional reform (e.g., strengthening forest police, certification schemes, and cross-border enforcement with the EU) have had mixed success. In Romania, EU pressure has resulted in formal action

(infringement cases, action plans), but illegal cutting remains widespread. By contrast, Ukraine – outside the EU – still struggles with legacy Soviet-era bureaucracy. Governance remains centralized, and forest authorities have limited capacity; this hampers the effective prosecution of illegal logging across the Carpathians and Polissia regions. In sum, both countries illustrate that formal laws (restitution, protected areas) can be hindered by institutional weaknesses.

Finally, policymakers are just beginning to grapple with climate adaptation. Shvidenko et al. (2017) warn that Eastern European forests (especially Ukraine's) are becoming increasingly vulnerable to droughts and heat: without "consistent policies of adaptation and mitigation," the region's forests could suffer catastrophic losses. They stress that a solid framework – including clear legislation, planning processes, and monitoring – is urgently needed. Indeed, Knutzen et al. (2025) show that recent heat-and-drought extremes in Europe have caused widespread tree mortality, even in relatively resilient ecosystems. Their analysis concludes that "European forests are highly vulnerable" and that *"tailored strategies"* (region-specific planning, enhanced monitoring) are essential to mitigate future impacts. Thus, adaptation planning and institutional reform are now critical policy fronts.

In summary, Eastern European states have pursued multiple forest-sector policies (restitution, new protected areas, EU integration) but systemic governance weaknesses often blunt their effectiveness. Romania's restitution laws and Ukraine's privatization have led to surges in harvesting and leakage into primary forests. Protected area expansions have succeeded in mapping more land for conservation, yet illegal logging inside parks remains common. Enforcement mechanisms are constrained by under-resourced institutions and complex land tenure, as noted by Bouriaud. While some afforestation and reforestation programs have yielded modest gains, the overall record is mixed: successes in carbon sink recovery coexist with persistent illegal logging and forest loss. As highlighted across the literature, further reforms (enhanced transparency, local participation, EU law compliance) and clear climate adaptation strategies will be needed to overcome these challenges.

CONCLUSION

The literature indicates that deforestation in Eastern Europe is driven by a complex mix of socioeconomic transitions and emerging climate pressures. The collapse of socialist land regimes left highly fragmented and often unclear tenure, and weak governance has enabled pervasive illegal logging and unsustainable land-use practices. These forces have taken a heavy ecological toll – forests have suffered dramatic biodiversity loss, widespread soil erosion, and water-cycle disruption, and reduced resilience to heat, drought, and extreme weather. Notably, Romania and Ukraine exemplify these challenges: Romania's protracted restitution and tenure transfers have undermined protected areas, with experts noting that "weak institutions" and economic pressures have allowed illegal logging to persist, while Ukraine's post-Soviet system remains beset by corruption and semi-legal timber exploitation despite nominal protection. Although EU integration, conservation programs, and tools like satellite monitoring have yielded some gains, their impact is blunted by underfunded agencies and graft. Indeed, new analyses show that climate change is magnifying threats – expanding pest ranges, increasing dieback, and wildfire risk across the region.

Together, these findings underscore the urgent need for bold policy action: reforms to strengthen forest governance and law enforcement, sustained anti-corruption efforts, and deeper

international collaboration are essential. Equally important are investments in technological systems (for example, Romania's satellite-based "Forest Inspector" monitoring platform) and active engagement of local stakeholders. Finally, integrating climate-adaptive management – planning forests to withstand hotter, drier conditions – must be a priority. Only through such coordinated, multi-level measures can Eastern Europe's forests be conserved and their ecosystem services preserved in the face of mounting pressures.

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TASTEGAN: GAN-BASED FLAVOUR ENHANCEMENT AND QUALITY PREDICTING MODEL

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ABSTRACT
In recent years, deep learning has brought innovation to many fields. Deep learning has made it possible to separate groups according to similar interests or characteristics. The deep learning based Generated Adversarial Networks (GAN) has achieved significant results in segmentation. With this approach Generative Adversarial Networks (GANs) have recently become a very popular research subject. In this study, A Generative Adversarial Network (GAN) was used to generate "near ideal quality" fake wine profiles based on the real wine characteristics (chemical data in the dataset) using Red Wine Quality Dataset. The dataset contains 1599 samples and 12 variables. In this case, near-ideal fake samples generated with the help of Gan were added to the original dataset and the classification model was made more balanced. For the purpose of the objective is to model the quality of wine on the basis of physico-chemical tests. A study was carried out to determine which chemical and how much should be changed to improve the quality. The quality prediction is then carried out with a custom-built DNN for the transformer block. The proposed model in comparison with the Multi-Layer Perceptron (MLP) and Logistic Regression models. GAN-based transformer hybrid model outperforms other conventional models.
Keywords: Generative Adversarial Network, Wine Quality Prediction, Deep Neural Network

1. Introduction

In recent years, deep learning techniques have made significant achievements in the field of artificial learning. A well-known generative deep learning model is the Adversarial Generative Network (GAN). The GAN model, also known as synthetic data, is capable of generating very high quality results. This is made up of generator and discriminator patterns that distinguishes between the synthetic data and real data. In contrast to the classical deep network architectures, it has two different deep networks, a generative (G) and a discriminative (D) one, and it carries out the learning process by working in an adversarial way between these two networks. The GAN has been remarkably successful in producing high quality synthetic data in many areas, including image and video generation, art and style transfer, text generation, data augmentation , and music composition. In spite of their success, GANs also have their challenges and limitations. GAN may be subject to mode collapse, where the synthesizer generates limited variation in the synthetic data, as well as vanishing gradients and variability during training (Azahad & Hameeda 2023). Nair et al 2019 investigate investigate a Generative Adversarial Network (GAN) architecture for multiangle planar ultrasound imaging. They trained the network with more than 50,000 FieldII simulations. Each simulation contained a unique cyst in the underlying tissue exposed to a unique plane wave.

The purpose of this study is to create a novel machine learning model that is different from traditional machine learning models (MultiLayer Perceptron, Logistic Regression, Random Forest, etc.) and has not been used before in the literature. The model uses GAN (Generative Adversarial Network) to create fake wine profiles that are "close to ideal quality" based on real wine characteristics (chemical data in the dataset) using on the Red Wine Quality dataset. This GAN based approach allows the classification model to be more balanced and powerful overall by adding "fake but ideal" examples to the dataset. Finally, a custom Transformer Block DNN is used for robust prediction.

2. Literature Review

GANs, first presented by Goodfellow et al. in 2014, have become a potent deep learning framework. They can produce incredibly lifelike synthetic data via a competitive training process between two neural networks, the discriminator and the generator. Tanaka and Aranha (2019) generate artificial training data for use in machine learning. Generative Adversarial Networks (GAN) are used to accomplish this. In circumstances like unbalanced data sets, it can be very helpful. A decision tree (DT) classifier that was trained using both the original dataset and training data produced by a GAN was evaluated for performance. In certain instances, it was found that the model trained using the GAN unexpectedly achieved a higher accuracy score.

In another study, 330 MRI scans from the SPIE ProstateX Challenge will be used to train a Deep Convolutional Generative Adversarial Neural Network (DCGAN) using state-of-the-art techniques. The ADC mode correctly darkens the centre of the lesion, while the synthetic T2 mode captures the rough, broken texture of the real patches (Kitchen and Seah (2017).

GAN-generated forged images were detected using a combination of a hybrid model, coincidence matrices and deep learning. The results obtained experimentally on two different and challenging GAN datasets of more than 56,000 images based on image-to-image unpaired translations and facial expressions have demonstrated that approach is achieving more than 99% classification accuracy on both datasets (Nataraj, 2017).

An innovative approach to the mode collapse problem is proposed. It uses a mixture of GANs generators. The main purpose of this is to use a number of generators, rather than just a

single one as in the original GAN. The proposed model uses parameter sharing to add minimal computational cost to the standard GAN and scale efficiently to large datasets (Hoang et. al 2018).

A new image processing system is proposed that generates images by inputting the users' freeform masks, drawings and colors. High quality synthetic images are generated using intuitive user input with the proposed system and SC-FEGAN network architecture (Jo and Park, 2019).

3. Materails and Methods

3.1. Dataset

In this study , we use Red Wine Quality Dataset which contains physicochemical and sensory data related to red varieties of the Portuguese wine. The Red Wine Quality dataset comprises 1,599 observations, each representing a red wine sample characterized by physicochemical properties and a quality score. The average fixed acidity is 8.32 (std = 1.74), with most values ranging between 7.1 and 9.2, while volatile acidity, which inversely affects wine quality, has a mean of 0.53 and ranges from 0.12 to 1.58. The citric acid content is relatively low on average (0.27), with a minimum of 0, suggesting some wines lack it entirely. Residual sugar, indicative of sweetness, has a median of 2.2 g/L but shows the presence of outliers with a maximum of 15.5. Chlorides, representing salt content, have a low average of 0.087 but can reach up to 0.611 Additionally, the dataset shows significant variation in total sulfur dioxide (mean = 46.47) and free sulfur dioxide (mean = 15.87), both of which are essential for microbial stability and preservation. Density is closely related to alcohol and sugar content, with little variation around a mean of 0.9967. Red wines typically have a pH of 3.31. Sulfates, which affect taste and microbial control, have an average of 0.66 but can reach 2.00. With a mean of 10.42% and a wide range of 8.4% to 14.9%, alcohol content is a significant factor in determining the perceived quality of wine. The majority of wines are of average quality, according to the quality scores, which range from 3 to 8 on a scale of 0 to 10. The distribution is slightly skewed to the right, with a center of 5 to 6 in table 1. As we can see from Figure 1, the correlation coefficient takes values between -0.6 and 1. It became clear that there is a strong relationship between citric acid and fixed acidity. And the similar strong relationship between total sulfur dioxide and free sulfur dioxide.However, there is no strong enough relationship for these variables to be eliminated. Figure 2 shows the quality of the red wine dataset. When we looked at Figure 2, we noticed an imbalance in the distribution. Outputs 5 and 6 are high.

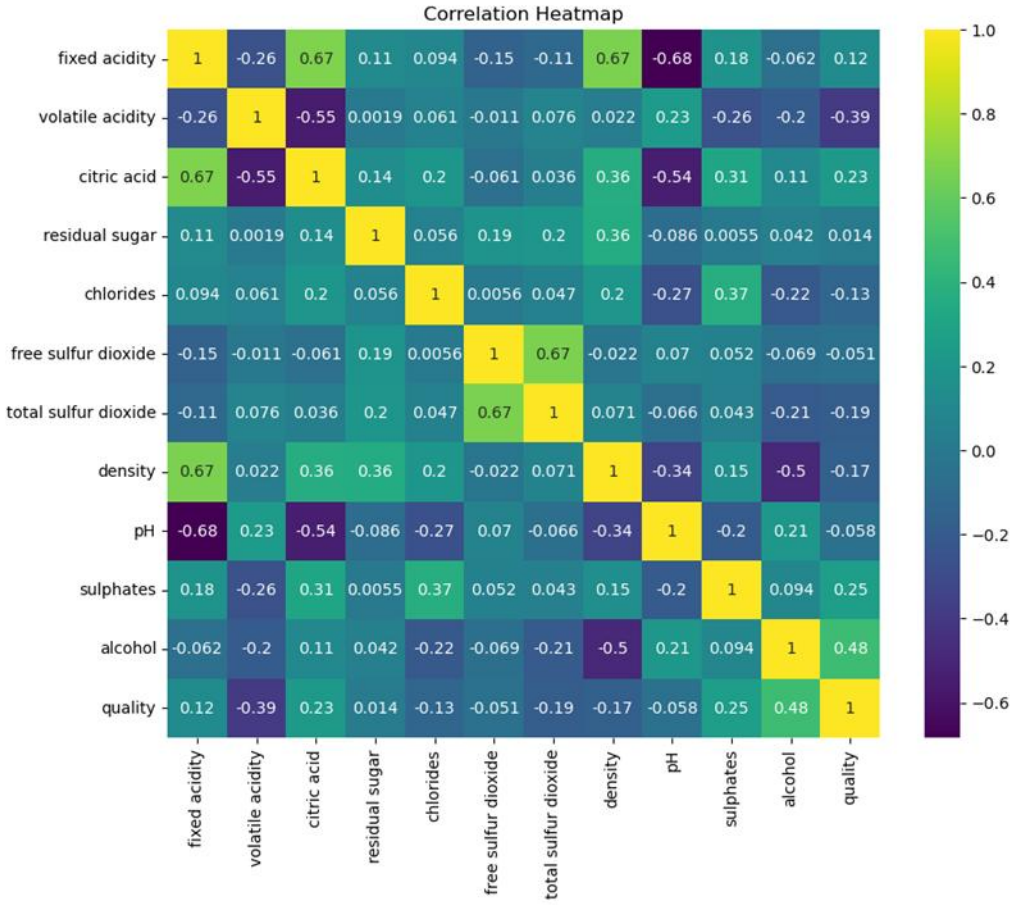

Figure 1. Corelation matrix of the features

Table 1 Statical propoerties of the Red wine Quality Dataset

Variables	Count	Mean	Std	Min	Max
Fixed acidity	1599.0	8.319.637	1.741.096	460.000	1.590.000
Volatile acidity	1599.0	0.527821	0.179060	0.12000	158.000
Citric acid	1599.0	0.270976	0.194801	0.00000	100.000
Residual sugar	1599.0	2.538.806	1.409.928	0.90000	1.550.000
Chlorides	1599.0	0.087467	0.047065	0.01200	0.61100
Free sulfur dioxide	1599.0	15.874.922	10.460.157	100.000	7.200.000
Total sulfur dioxide	1599.0	46.467.792	32.895.324	600.000	28.900.000
Density	1599.0	0.996747	0.001887	0.99007	100.369
Ph	1599.0	3.311.113	0.154386	274.000	401.000
Sulphates	1599.0	0.658149	0.169507	0.33000	200.000
Alcohol	1599.0	10.422.983	1.065.668	840.000	1.490.000
Quality	1599.0	5.636.023	0.807569	300.000	800.000

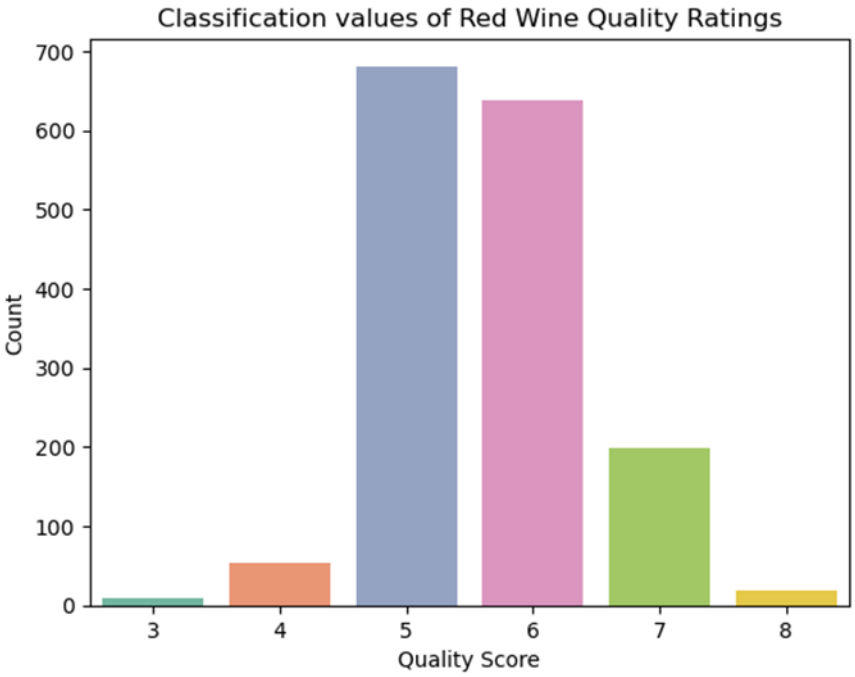

Figure 2. Classification values of red wine quality dataset

3.2. Purposed models

In this section, a GAN-based transformer model is designed. This model is used to predict the quality of a red wine dataset. A Generative Adversarial Network (GAN) was employed for data augmentation by generating synthetic (dummy) samples, thereby replacing traditional regression-based approaches for enhancing the dataset. We propose a novel hybrid approach that integrates data synthesis with predictive modelling by combining Generative Adversarial Networks (GANs) and Transformer architectures, enabling both realistic data generation and accurate forecasting. The structure shown in Figure 3 is a Generative Adversarial Network (GAN)-style architecture, made up of two separate components. In the first step of the model, the generative neural network finds data features and assesses the training set. Analyzing the original training data and independently differentiating between features is how a discriminative neural network works. The generative network alters some data attributes by introducing noise (or random changes) to those attributes. In the second step, the discriminator network receives the change data from the generative network. Discriminator network calculates probability that generated output belongs to original dataset. In order to lower the noise vector that is randomly generated in the following step, the discriminator network directs the generator network.

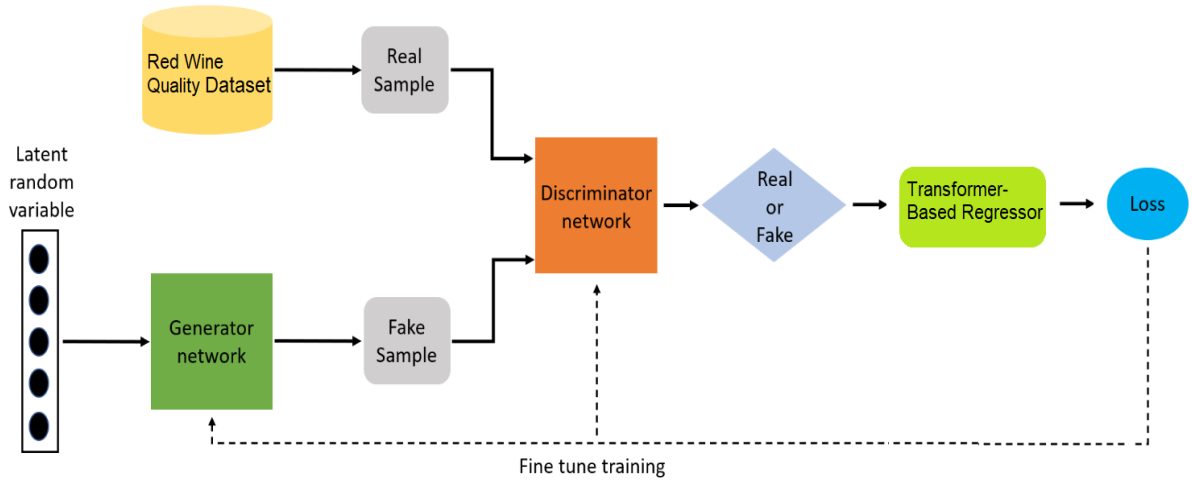

Figure 3. The proposed model flowchart

3.3. Benchmarking models

3.3.1. Logistic regression

A popular statistical technique for simulating binary or categorical outcome variables is logistic regression. In contrast to linear regression, which forecasts continuous results, logistic regression uses a logistic (sigmoid) function to constrain the output between 0 and 1 in order to estimate the likelihood that a specific class or event will occur (Hosmer et al., 2013). It works especially well when the dependent variable is binary, like success or failure or yes/no results. Numerous domains, such as marketing analytics, credit scoring, and medical diagnosis, have made extensive use of logistic regression due to its interpretability and computational efficiency (Menard, 2002). Its coefficients provide important information about the relationship between predictors and the response variable and can be expressed as log-odds. Even though increasingly intricate machine learning models have emerged, logistic regression remains a foundational and benchmark approach for classification problems.

3.3.2. Multilayer Percepton

An input layer, one or more hidden layers, and an output layer make up a Multilayer Perceptron (MLP), a type of feedforward artificial neural network. MLPs are able to learn intricate, nonlinear relationships between input and output variables because each neuron in the network employs a nonlinear activation function. In order to minimize prediction error, MLPs are trained using supervised learning techniques like backpropagation, which modifies the weights through gradient descent (Rumelhart et al., 1986). Due to their flexibility and ability to approximate any continuous function, MLPs have been widely applied in various domains, including classification, regression, and time-series forecasting (Gardner & Dorling, 1998). The architecture (number of

layers and neurons) and the selection of activation and optimization functions have a significant impact on their performance, making them a foundational model in modern machine learning and deep learning research.

4. Discussion

The performance of the proposed approach is evaluated based on the GAN-Transformer model, which is also defined in this study. The proposed approach is applied to this evaluation. The Red Wine Quality Dataset is used for implementation. The comparison was between three models. These models are LR, MLP and GAN+Transformer model. The evaluation of the models was made according to the mean squared error (MSE) Loss metric, which is a key performance indicator in machine learning. The formula MSE is shown in eq.1. As can be seen in Figure 4, our model has achieved a lower MSE Loss value than the other two models.
Where n is vector of predictions, Y is the observed values and P is the predicted value

$$\text{MSE} = \frac{1}{n}\sum_{i=1}^{n}(Y_i - P_i)^2 \quad (1)$$

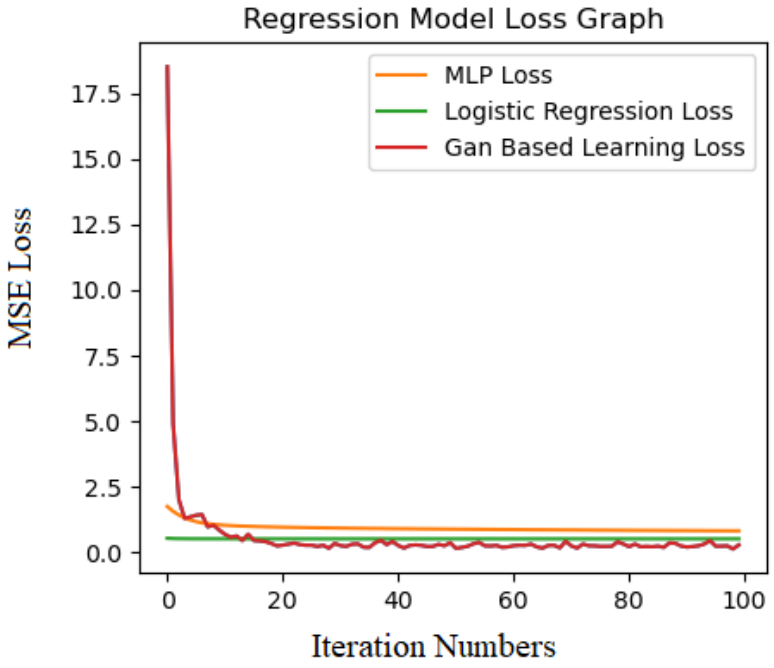

Figure 4. A comparison of the proposed model and the benchmarking model.

5. Conclusion

In this study, in contrast to conventional machine learning techniques, the suggested model, which combines Generative Adversarial Networks (GAN) for data augmentation and a Transformer-based architecture for prediction, showed better performance. In particular, the suggested method continuously obtained lower loss values when compared to the Multilayer Perceptron (MLP) and Logistic Regression models, suggesting enhanced accuracy and

generalization ability. While the Transformer model successfully captured intricate dependencies within the input features, the use of GANs improved the training data's diversity and quality. These findings demonstrate how deep learning-based data augmentation and attention mechanisms can be combined to improve performance over traditional models in structured prediction tasks.

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ÖZET

Bu çalışma, otomotiv endüstrisinde hafiflik, enerji verimliliği ve çevresel regülasyonlara uyum hedefleri doğrultusunda artan yüksek mukavemetli çelik (AHSS) kullanımı çerçevesinde, sac metal şekillendirme süreçlerinde karşılaşılan kenar çatlağı oluşum mekanizmalarını analiz etmektedir. Günümüzde demir dışı metaller ve kompozit malzemeler alternatif olarak değerlendirilse de, çelik malzemeler halen otomobil üretiminde kütlesel olarak dominant konumda bulunmaktadır. Bu durum, çeliklerin şekillendirme sırasında maruz kaldığı gerilme durumlarının ve kenar kalitesinin üretim verimliliği açısından kritik olmasını beraberinde getirmektedir.

Başta mevcut otomobillerde, özellikle de şasi ve yüksek dayanım beklentisi olan gövde parçalarında karşımıza çıkan yüksek mukavemetli çelik (AHSS) grubundan DP çift fazlı; CP kompleks faz ve otomotiv sektöründe hız kazanan elektrikli araçların batarya taşıyıcılarında kullanılacak türü olan martenzitik çeliklerin (MS) kenar çatlak dayanımları, malzeme ve proses parametreleri bağlamında karşılaştırılmıştır. Benzer mekanik özelliklere sahip olmalarına rağmen, mikro yapısal farklılıkları nedeniyle deformasyon ve hasar gelişim süreçlerinde ayrışan bu çeliklerin, özellikle açınım geometrisi ve bükme açısı parametrelerinin kenar çatlak oluşumuna etkileri, sonlu elemanlar analizi (FEA) yoluyla sistematik olarak değerlendirilmiştir.

Analiz sonuçları, malzeme davranışı ile proses koşullarının kenar çatlağı üzerindeki karmaşık etkileşimini ortaya koymakta olup, elde edilen bulgular ilerleyen aşamada gerçekleştirilecek deneysel çalışmalarla desteklenerek, yüksek mukavemetli çeliklerin şekillendirme sırasında kenar çatlağına karşı dayanımını artıracak tasarım ve proses stratejilerinin geliştirilmesine temel oluşturarak, önlenebilir üretim kayıplarını yakalamak amaçlanmaktadır.

Anahtar Kelimeler: Yüksek mukavemetli çelikler (AHSS), kompleks faz (CP), çift faz (DP), martenzitik çelik (MS), sonlu elemanlar analizi (FEA), kenar çatlağı (edge crack)

INVESTIGATION OF EDGE CRACK PARAMETERS OF HIGH STRENGTH STEELS

ABSTRACT

This study investigates the mechanisms of edge crack formation encountered in sheet metal forming processes, within the context of the increasing use of advanced high-strength steels (AHSS) in the automotive industry to meet the objectives of lightweighting, energy efficiency, and compliance with environmental regulations. Although non-ferrous metals and composite materials are considered as alternatives, steels remain the dominant material in automotive manufacturing due to their advantageous balance of energy absorption capacity and cost efficiency. Consequently, the stress states and edge quality of steel sheets during forming processes have become critical factors influencing production efficiency and component reliability.

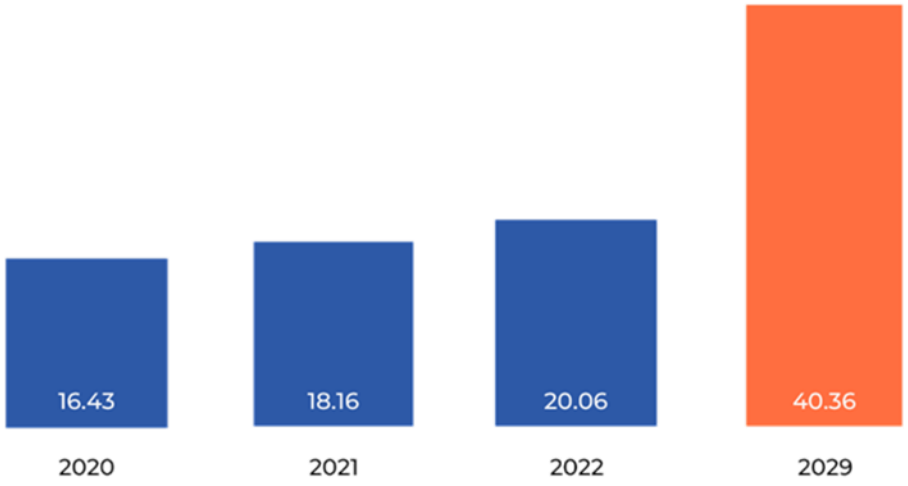
In this context, the edge crack resistance of three different AHSS grades commonly used in current automotive applications, dual-phase (DP) steels, complex-phase (CP) steels, and martensitic (MS) steels, which are increasingly favored in the structural components of electric vehicle battery systems, has been comparatively examined with respect to material characteristics and process parameters. Despite exhibiting similar levels of mechanical strength, these steels demonstrate distinct deformation and damage evolution behaviors due to their microstructural differences. In particular, the effects of blank geometry and bending angle on edge crack formation have been systematically evaluated using finite element analysis (FEA).

The analysis results reveal the complex interactions between material behavior and process conditions in determining edge crack susceptibility. The findings of this numerical study will be further validated and supported by subsequent experimental investigations. Ultimately, the outcomes of this research are expected to provide a scientific foundation for developing design and process optimization strategies aimed at enhancing the edge crack resistance of advanced high-strength steels during forming operations, thereby minimizing avoidable production losses.

Keywords: Advanced high-strength steels (AHSS), complex-phase steel (CP), dual-phase steel (DP), martensitic steel (MS), finite element analysis (FEA), edge crack

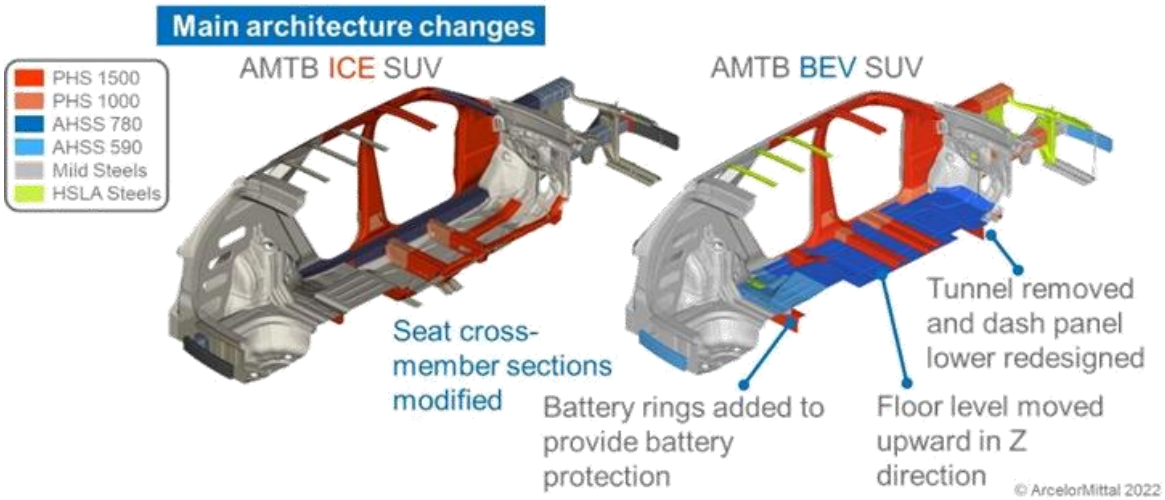
1. GİRİŞ

Son on yılda ileri yüksek mukavemetli çeliklerin (AHSS) otomotiv yapısal parçalardaki payı %70'in üzerinde arttığı bilinmektedir. (Exactitude Consultancy, 2023). Ağırlık azaltımı ve batarya koruma gereksinimleri karşısında DP, CP ve MS çelikler tercih edilse de, en büyük kalite problemlerinde biri olan kenar çatlağı oluşumu, üretim hattında fire oranlarında %20-40 bandında dalgalanmaya yol açmaktadır. Kenar çatlakları; kesim sonrası hasar, mikroyapı faz sertlik farkı, form verme şekli ve hidrojen gevrekliği gibi çevresel etkilerin karmaşık etkileşimiyle başlar (Kim & Lee, 2020; Microstructural Aspect of HE, 2025).



Şekil 1: 2020-2029 arasında otomotiv AHSS pazar büyüklüğü (Exactitude Consultancy, 2023)

Ağırlık azaltımı hedefleri, çelik kullanımım oranında azalma görebileceğimiz sonucunu düşündürse de, sektör de yüksek mukavemetli çelikler, elektrikli araçların hayatımıza girmesi ile batarya taşıyıcılardan beklelnen yüksek mukavemetler dolayısıyla gündemimizde uzun bir süre kalmaya devam edecektir.

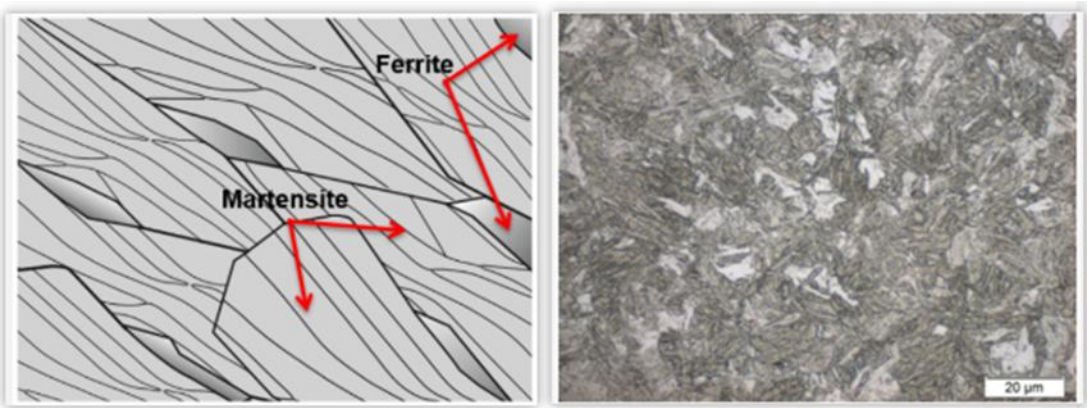


Şekil 2: 2020-2029 arasında otomotiv AHSS pazar büyüklüğü (Exactitude Consultancy, 2023)

Bu grup çelikler içerisinden hali hazırda oldukça yaygın olan DP, daha çok profil ve aracın alt gövdesi diye tanımlan gruptaki gövde destek parçalarını oluşturan CP ve batarya taşıyıcı profilleri oluşturacak olan yeni aşina olmaya başladığımız MS çelikler ele alınacaktır. Çalışmanın ana konusu olan mikroyapı bazlı performans değerlendirmesini görebilmek için benzer mekanik özellikteki ancak farklı mikroyapıya sahip saclar seçilerek yapılmıştır.

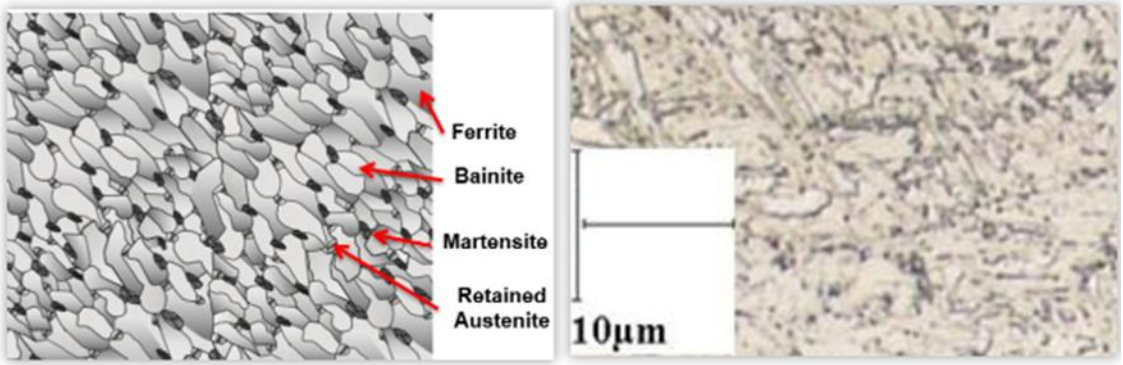
1.1. DP, CP, MS Çeliklerin Özellikleri

Çift Fazlı (DP) Çelikler, mukavemet ve sünekliğin mükemmel dengesi nedeniyle otomotiv uygulamalarında halihazırda yaygın olarak kullanılmaktadır. Bu çelikler, dislokasyon sertleştirme, ikizleme ve gerilme sırasında martensit dönüşümü dahil olmak üzere sertleştirme mekanizmalarının bir kombinasyonu yoluyla yüksek mukavemete ulaşırlar. Schmitt ve Lung (2018); (Hao vd. (2022).



Şekil 3: DP Çift Fazlı Bir Malzemenin Mikro yapısı (WorldAutoSteel, 2024)

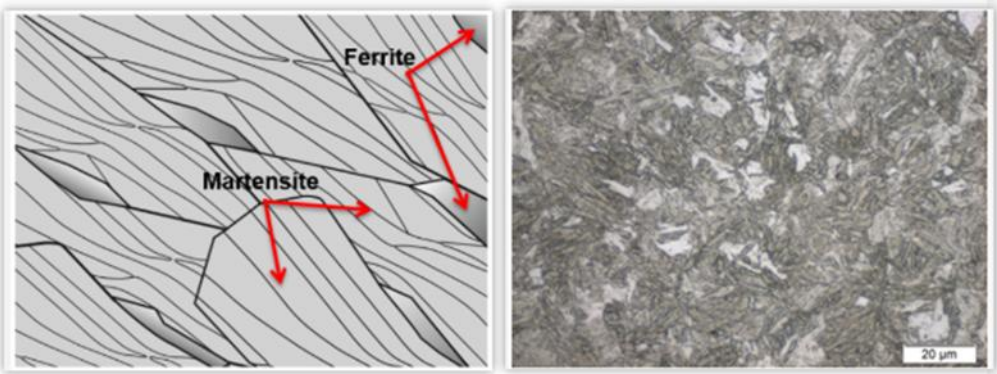
Karmaşık fazlı (CP) çelikler, beynit, martenzit, ferrit ve kanlıntı ostenit içeren çok fazlı bir mikro yapı ile karakterize edilen bir tür gelişmiş yüksek dayanımlı çeliktir. Bu çelikler, yüksek dayanım ve iyi şekillendirilebilirliğin bir kombinasyonunu sunmak üzere tasarlanmıştır ve bu da onları özellikle otomotiv uygulamalarında kullanışlı hale getirirmektedir. (Ishijima, 1990).



Şekil 4: CP Çift Fazlı Bir Malzemenin Mikro yapısı (World Auto Steel, 2024)

Martenzitik çelikler, ostenitin hızla soğutulmasıyla oluşan martensitik bir mikro yapı ile karakterize edilen bir çelik türüdür. Bu mikro yapı, yüksek mukavemet ve sertlik sağlayarak martensitik çelikleri çeşitli zorlu uygulamalar için uygun hale getirir. Ultra yüksek dayanımlı

martensitik çelikler sıcak şekillendirilmiş ve soğuk şekillendirilmiş çelikler olarak kategorize edilir. Bu malzemeler, mükemmel plastisiteleri ve gelişmiş şekillendirme teknolojileri nedeniyle akü çerçeveleri, kapı koruma kirişleri ve tamponlar gibi kritik otomotiv bileşenlerinde giderek daha fazla kullanılmaktadır. Schmitt ve Lung (2018). Ultra yüksek dayanımlı martensitik çeliklerin uygulanmasındaki zorluklardan biri, malzemenin performansını tehlikeye atabilen hidrojen gevrekleşmesidir. Devam eden araştırmalar, bu sorunu ele almayı ve bu çeliklerin otomotiv uygulamalarındaki güvenilirliğini artırmayı amaçlamaktadır.



Şekil 5: Martenzit Bir Malzemenin Mikro yapısı (World Auto Steel, 2024)

DP çelikler ferrit-martenzit adacıkları, CP çelikler ince taneli ferrit-beynit matrisi ve sınırlı martenzit, MS çelikler ise neredeyse tam martenzitik yapı içerir. (WorldAutoSteel, 2024). Bu faz dağılımları, delik genişletme oranı (HER) ve minimum bükme yarıçapı (R/t) parametrelerinde belirgin performans farkları yaratır (Hu et al., 2020).

Bu çalışma, kesim etkilenmiş bölge mikroskobisi ve hidrojen difüzyonu verilerini önceki modelleme çalışmalarımıza entegre ederek, farklı AHSS sınıflarının kenar çatlak eşiğini daha gerçekçi biçimde belirlemeyi amaçlamaktadır.

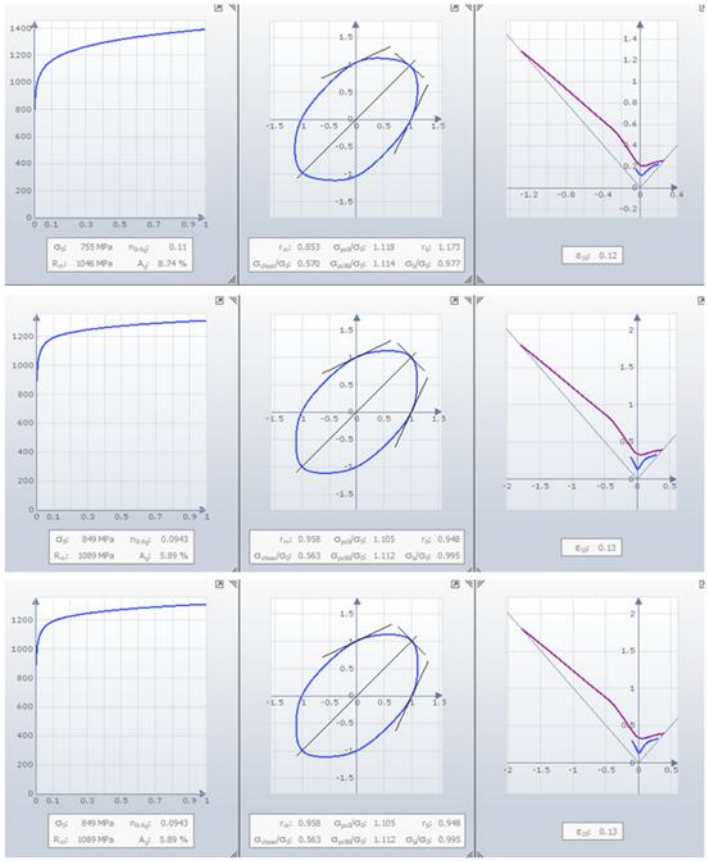
2. GELİŞME

2.1 Malzemeler ve Yöntem

Bu çalışmada kenar çatlağı oluşumunun güvenilir şekilde gözlemlenebilmesi amacıyla, gerilme yığılmalarını minimize edecek şekilde optimize edilmiş açınım geometrileri tercih edilmiştir. Kavisli ve yuvarlatılmış kenarlar, çatlak başlama noktalarını sınırlamak amacıyla tasarıma entegre edilirken, keskin köşelerden özellikle kaçınılmıştır. Deneysel karşılaştırmaların standardize edilebilmesi adına sac kalınlığı tüm numunelerde 2 mm olarak belirlenmiştir.

Bükme davranışının değerlendirilmesi için 60°, 90° ve 120° olmak üzere üç farklı bükme açısı seçilmiştir. Bu açılar sırasıyla düşük deformasyonun çatlak başlangıcına etkisini, orta deformasyon seviyelerinde çatlak ilerlemesini ve aşırı deformasyon koşullarında malzeme dayanım sınırlarını test etmeye olanak tanımaktadır. Literatürde raporlanan mikroyapıya bağlı minimum bükme yarıçapı oranları dikkate alınarak (Hu vd., 2020), tüm malzemeler için başlangıç denemelerinde kullanılmak üzere 4 mm (2 × kalınlık) yarıçap değeri referans alınmıştır. Malzeme türüne bağlı olarak bu değer CP çeliklerde daha geniş, MS çeliklerde ise daha büyük yarıçaplarla genişletilebilir. Deneme sürecine bağlı olarak farklı yarıçaplar da ilerleyen aşamalarda değerlendirilebilir.

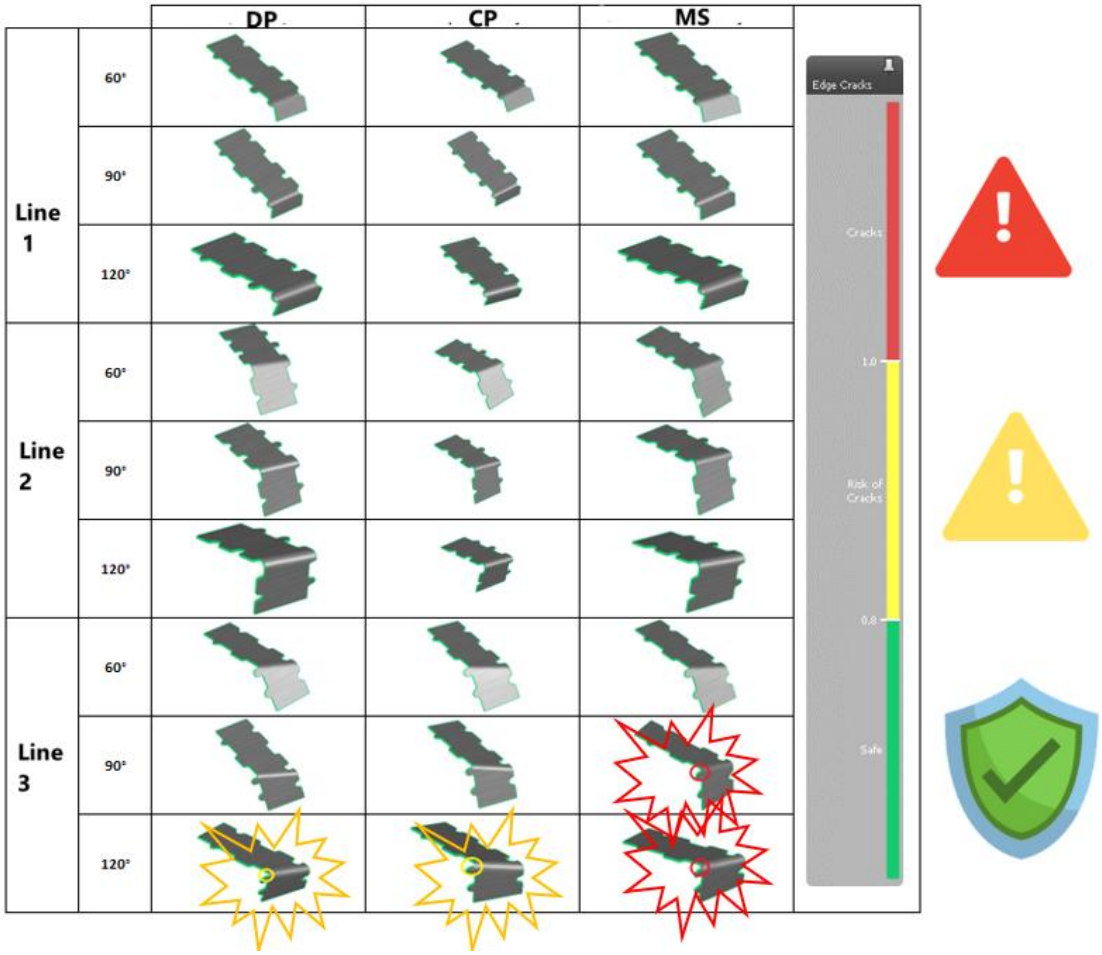
Sonlu elemanlar analizi yukarıda bahsedilen bükme açıları ve hatları doğrultusunda yapılmıştır. Sonlu elemanlar analizinde kullanılan malzeme kartları ve malzemelerin meknaik özellikleri Şekil'6 daki gibi gösterilmiştir.



Şekil 6: FEM analizinde kullanılan CP, DP, MS malzemelerin SSAB tarafından hazırlanan malzeme kartları (SSAB, 2024)

AutoForm, sac metal şekillendirme süreçlerinde özellikle yüksek mukavemetli çeliklerin kesilmiş kenarlarındaki çatlak riskini değerlendirmek için kullanılan bir analiz yazılımıdır. Bu yazılım, klasik incelme veya kırışıklık analizlerinden farklı olarak, kenar çatlaklarına özgü daha hassas bir yöntem sunar. Analiz sırasında, kontur boyunca oluşan eşdeğer gerinme değerleri kritik uzama değerleriyle karşılaştırılır ve bu oran "Edge Crack" riski olarak yorumlanır. Aynı zamanda şekillendirme işleminin geçmişi dikkate alınarak, her adımda malzemede biriken plastik şekillendirme işinin toplamı hesaplanır. Bu değerlendirmede kesme kalitesi, malzeme özellikleri ve delik genişleme testlerinden elde edilen kritik gerinim verileri temel alınır. Elde edilen sonuçlar, kontur üzerinde renkli haritalarla görselleştirilir ve 1'in üzerindeki değerler, çatlak oluşma riskinin yüksek olduğunu gösterir.

2.2 Sayısal ve Deneysel Bulgular



Şekil 7: Farklı bükme açıları, farklı bükme hatları ile yapılan sonlu elemanlar analizi (Autoform)

Sonlu elemanlar analizine göre:
DP Çelikler (Çift Fazlı Çelikler):
60° ve 90° bükme açılarında: Tüm hatlarda çatlak oluşumu beklenmemektedir. (güvenli bölge, yeşil alan).
120° bükme açılarında: Çatlak oluşumu gözlemlenmemiştir veya düşük risk taşımaktadır. DP çeliklerin yüksek süneklikleri bu performansı destekllemektedir.

CP Çelikler (Kompleks Fazlı Çelikler):
60° ve 90° bükme açılarında: Genel olarak çatlak riski düşüktür; güvenli bölgede yer almaktadır.
120° bükme açılarında: Çatlak riski artış gösterebilir, ancak kritik seviyeye ulaşmamıştır. (daha çok sarı alanda).

MS Çelikler (Martenzitik Fazlı Çelikler):
60° ve 90° bükme açılarında: Bazı hatlarda çatlak riski bulunmaktadır, özellikle martenzitik çeliklerin düşük süneklikleri nedeniyle sarı alana yakın bölgeler gözlemlenmiştir.

120° bükme açılarında: MS çeliklerde çatlak oluşumu daha belirgindir (kırmızı alan). Düşük süneklik nedeniyle bükme işlemine daha duyarlıdır.

Yüksek dayanımlı çeliklerin kenar performanslarının optimize edilmesi için kesim kalitesi, takım tasarımı ve bükme açılarının dikkatle değerlendirilmesi gerekir. Bu teori verileir ile deneysel sonuçlar bir sonraki çalışmada karşılaştırılacaktır.

Tablo MS malzemeler dışında kenar çatlağında çok yüksek bir risk göstrermese bile biliyoruz ki, farklı açılarla ve çeşitli yaklaşımlarla yapılan sonlu eleman analizleri yürütülse bile, modele dahil edilemeyen çevresel faktörler kenar çatlağı performansı üzerinde hala güçlü bir etkiye sahiptir. Bu nedenle, sanal olarak analiz edilen aynı parça, sayısal bulguların doğrulanması amacıyla çalışmanın bir sonraki aşamasında kenar çatlağı açısından fiziksel olarak test edilecektir.

3. SONUÇ

Kenar çatlağı oluşumunu etkileyen en önemli faktörler arasında **mekanik özellikler** ve **mikroyapı** başta gelmektedir. Ancak yapılan simülasyonlar, bu parametrelerin tamamını gerçeğe birebir yansıtmakta yetersiz kalabilmektedir. Çünkü **çevresel etkiler**, sayısal modellere doğrudan girdi olarak verilemeyen ve çatlak oluşumunu önemli ölçüde etkileyen değişkenlerdir. Bu nedenle simülasyon sonuçları her zaman gerçek uygulamaları tam olarak yansıtmaz ve destekleyici deneylerle mutlaka doğrulanmalıdır.

Çatlak oluşumuna katkı sağlayan ve simülasyonda tam temsili zor olan başlıca çevresel ve proses kaynaklı etkenler şunlardır:

- Bükme yarıçapı
- Ortam sıcaklığı
- Sac bekleme süresi (stokta bekletilme süresi)
- Segregasyon (bileşim ayrışması)
- Kesme takımı kalitesi
- Tireşim
- Hidrojen gevrekleşmesi

Bu faktörlerin her biri, kesilmiş kenarlarda gerinme birikimini artırarak çatlak oluşumunu tetikleyebilir. Dolayısıyla, yalnızca sayısal modellere değil, aynı zamanda çok yönlü deneysel verilere dayalı olarak süreç iyileştirmeleri yapılmalı ve **önleyici mühendislik önlemleri** bu doğrultuda şekillendirilmelidir

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FORECASTING AND OPTIMIZING RENEWABLE ENERGY STORAGE EFFICIENCY IN THE ERA OF CLIMATE CHANGE

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ABSTRACT
With the boom in climate change requiring a shift towards renewable energy sources, effective energy storage systems are the pathway to reliability and sustainability. In this work, an end-to-end strategy in energy storage prediction and optimization is explored with the help of machine learning. From open data provided on Kaggle's webpage, the research applies the Random Forest regression model in parameterizing storage capacity as a function of installed capacity, excess energy, and consumption rates, which are critical system parameters. The process is linear: data preprocessing, feature engineering, model selection, RandomizedSearchCV hyperparameter optimization, and visual analytics for result interpretation. Two new variables "Energy Surplus" and "Storage per Installed Capacity" were constructed to improve predictability. Better model performance with test R^2 of 0.9987 and mean absolute error (MAE) of 47.57 was achieved in the research, validating the power and predictability of the Random Forest model. One of the distinguishing factors of the project is its dual purpose: not only analyzing real storage data but also simulated scenarios by putting them through a simulation to obtain possible optimization solutions. The result illustrates the extent to which feature selection and model optimization are powerful drivers in creating high-accuracy predictions, which can be the game-changer in strategic decision-making in the energy sector. Plots like distribution plots and correlation heatmaps also facilitate model interpretability and transparency. This book is of excellent value to energy planners, engineers, and policymakers in carbon emissions minimization and system efficiency maximization management. And, its data-driven and reproducible quality gives it tremendous versatility for applications in long-term applicability in the energy system domain and other areas of sustainability.

Keywords: Renewable Energy, Energy Storage, Machine Learning, Random Forest, Optimization, Climate Change, Forecasting, Sustainable Systems, Data Analysis in Python.

1. Introduction

In the age of climate crisis, sustainable energy systems have emerged as a global priority. As countries move toward renewable sources such as solar and wind, energy storage becomes an essential pillar to ensure reliability, grid stability, and scalability. Yet, storage optimization remains a major challenge, requiring intelligent systems that can learn from data and predict operational requirements. This is particularly important as renewable sources are inherently intermittent, and effective storage forecasting can enable smarter distribution, reduced carbon emissions, and minimized energy loss.

The current research addresses this challenge by proposing a machine learning-based approach to predict and optimize energy storage capacity in renewable energy systems. Using a publicly available dataset, we built predictive models that forecast storage capacity based on key variables such as installed capacity, energy surplus, and grid efficiency. Our approach combines classical feature engineering with advanced modeling using Random Forest, chosen for its accuracy and robustness in high-dimensional data.

What sets this work apart is its holistic structure: not only are real-world data used, but new synthetic features are engineered, scenarios are simulated, and results are evaluated both statistically and visually. We also apply hyperparameter optimization using RandomizedSearchCV, maximizing the model's generalization ability. Our findings contribute to both the academic and industrial fronts, providing a blueprint for data-driven energy system management in the face of climate volatility.

2. Methodology

The research follows a structured end-to-end data science workflow. The data were sourced from Kaggle and include numerical features related to installed capacity (MW), energy consumption and production (MWh), grid integration level, storage efficiency, financial incentives, CO2 reduction, and more.

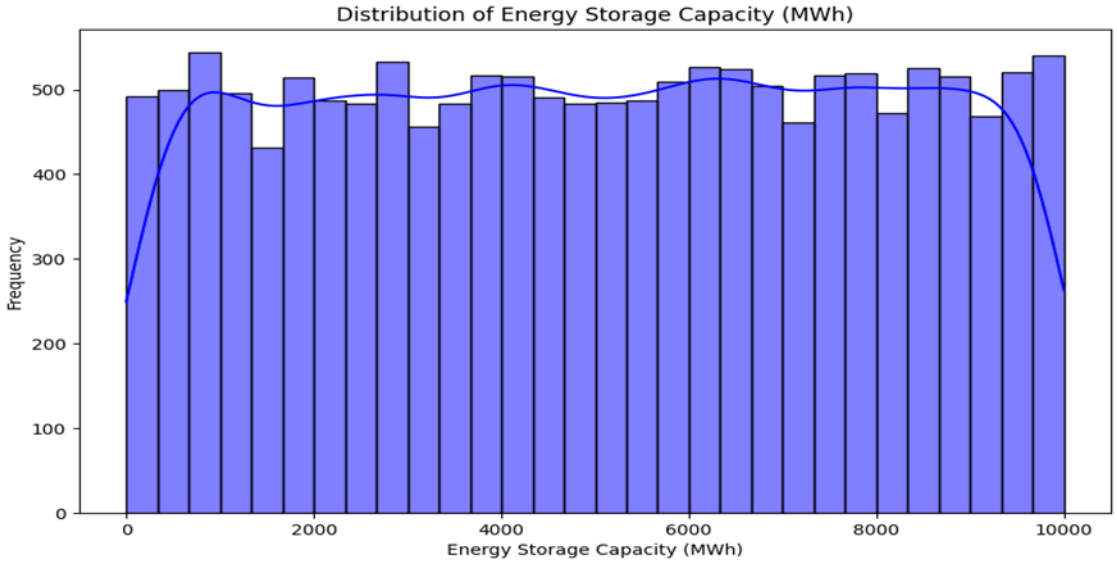
Data preprocessing involved several important steps. First, the data were cleaned by removing null values and correcting inconsistencies. Next, categorical variables were encoded numerically, and all features were normalized. Two novel features were engineered to enrich the dataset: "Energy Surplus," calculated as the difference between energy production and consumption, and "Storage per Installed Capacity," a ratio that captures how efficiently each unit of installed power contributes to storage capacity.

To predict energy storage capacity (MWh), we employed the Random Forest regression model. It was selected based on its ability to capture nonlinear relationships and resist overfitting. Model training was conducted with an 80/20 split for training and testing data. To further boost performance, RandomizedSearchCV was used to tune hyperparameters such as the number of estimators and maximum depth. The model was evaluated using metrics including Mean Absolute Error (MAE) and R^2 score. For additional robustness, cross-validation and residual analysis were conducted.

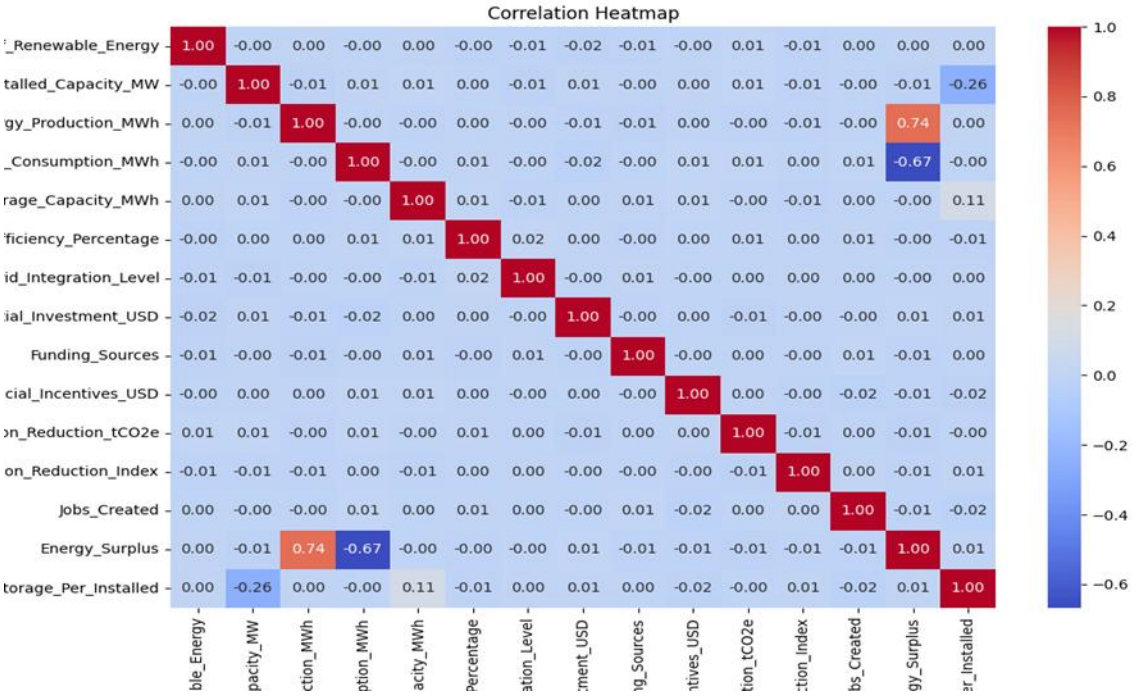
Visualization played a key role throughout the pipeline. Pairplots were generated to observe feature interactions, while a correlation heatmap provided insight into feature relationships. Feature importance was derived from the trained Random Forest model to explain which variables most influenced predictions. Distribution plots of the target variable and residual histograms were also used to assess bias and variance.

3. Results and Discussion

Initial exploratory data analysis showed uniform distribution in the target variable (energy storage capacity), confirming the suitability of regression modeling.

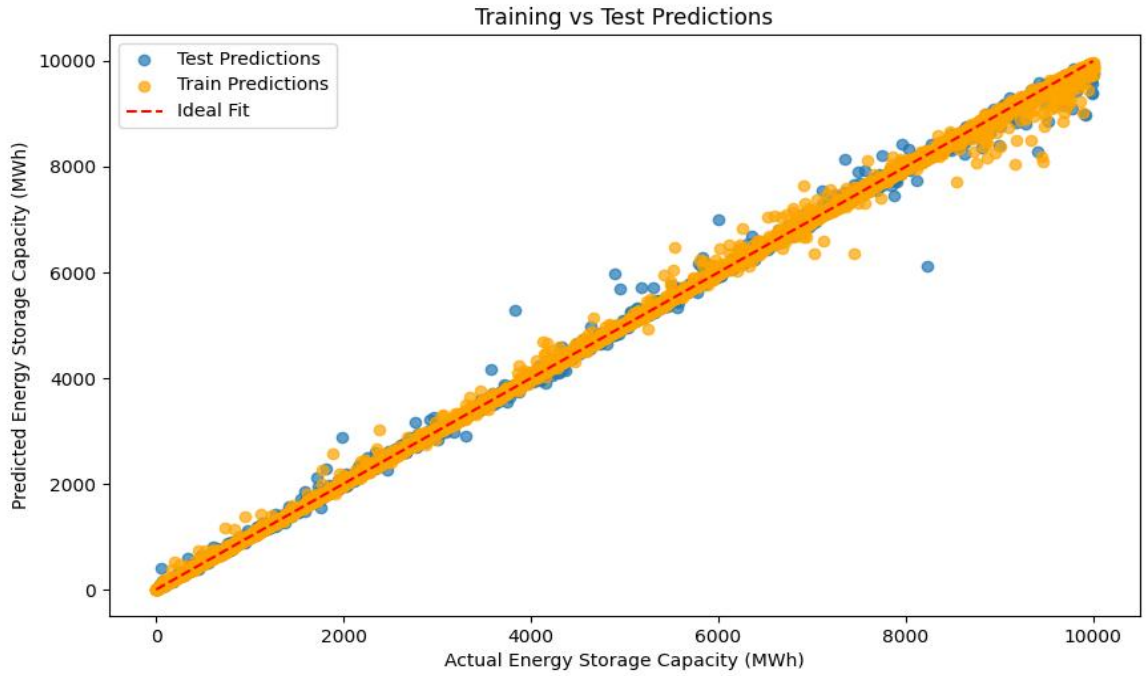


The correlation heatmap confirmed these findings, identifying significant positive correlation between installed capacity and storage, while variables like efficiency and emission reductions had weaker associations.

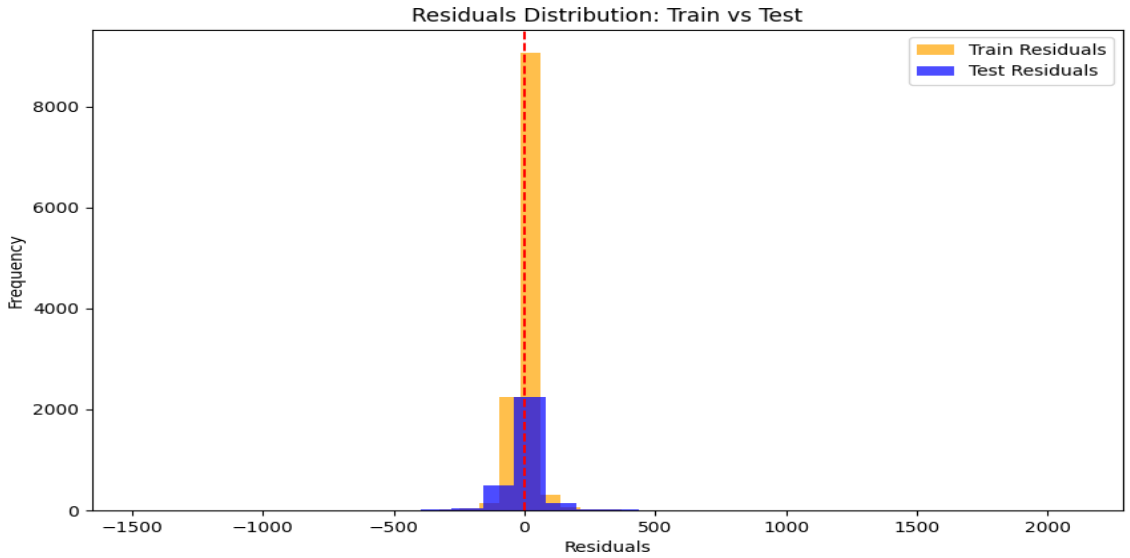


The model demonstrated exceptional predictive accuracy. On the test set, the Random Forest regressor achieved an MAE of 47.57 and an R^2 score of 0.9987. Predictions on both the

training and test sets closely followed the ideal diagonal line in the prediction plots, showing minimal deviation.

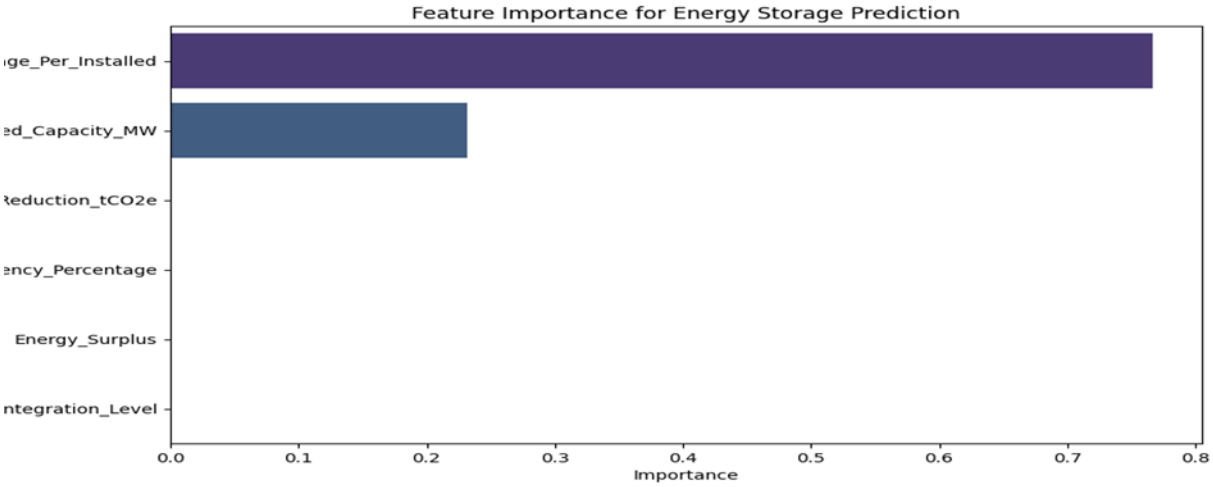


This confirms the model's high generalization performance, and its ability to accurately forecast energy storage needs across various input scenarios.
Residual analysis further supported these findings. The residuals of the training and test sets were tightly centered around zero, indicating low bias and variance.



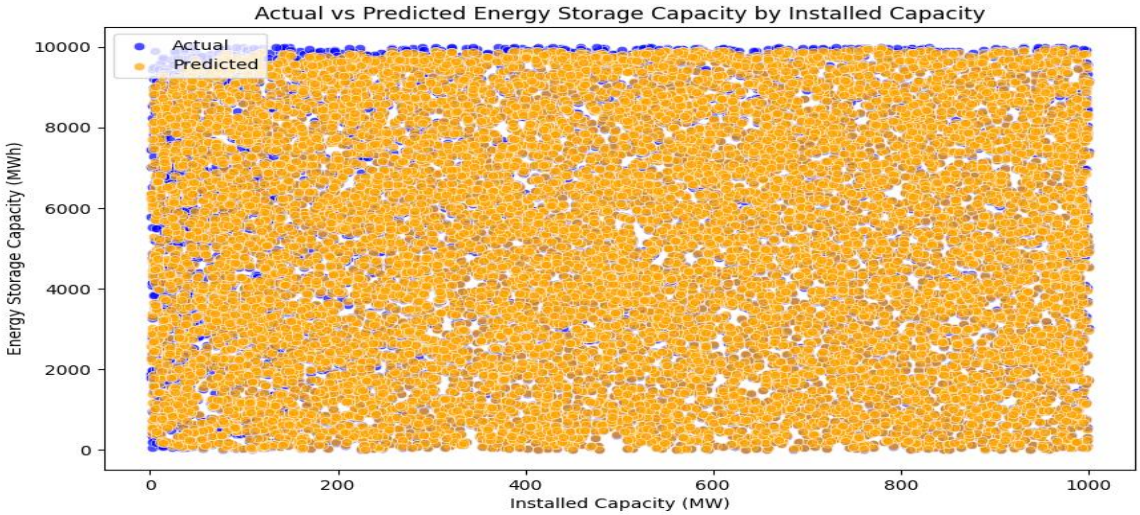
There was no sign of significant heteroscedasticity, and the residuals followed a normal distribution. This proves that the model is well-calibrated and unbiased.

Feature importance rankings highlighted the dominant role of "Storage per Installed Capacity" and "Installed Capacity (MW)" in determining energy storage outcomes. This insight into feature impact is vital, especially for strategic planning in renewable infrastructure. Identifying which variables hold the greatest influence allows for targeted improvements in system design and investment.



These two features alone accounted for the majority of the model's predictive power. Other features such as grid efficiency, energy surplus, and CO2 emission reduction showed lesser but still meaningful influence.

Visualization of the actual vs. predicted energy storage values based on installed capacity revealed a near-perfect fit. The visual comparison offers not just a statistical confirmation, but also an intuitive grasp of model fidelity. Predicted values consistently aligned with actual figures across diverse capacity ranges, strengthening confidence in model scalability.



where predicted values nearly overlapped with actual values across the full range of installed capacity. This visualization provides additional validation of the model's reliability and helps communicate the results to policymakers and energy engineers.

4. Conclusion

This study provides compelling evidence that machine learning, particularly Random Forest regression, can serve as a powerful tool in forecasting and optimizing energy storage within renewable energy systems. By leveraging real and engineered features, optimizing hyperparameters, and using advanced visualization techniques, we were able to build a high-performing model that supports both environmental and operational decision-making.

The research offers multiple contributions: (1) a methodological blueprint for applying ML in renewable energy storage analysis; (2) the identification of high-impact predictive features; and (3) an interpretability framework via visual analysis. While the model performed exceptionally on the given dataset, its extension to other regions and systems should be tested in future work.

Ultimately, the project presents a scalable, reproducible, and interpretable system that energy planners and environmental policymakers can use to inform resource allocation, design better infrastructure, and enhance sustainability strategies amid the challenges of climate change.

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PREDICTING FOREST FIRE RISKS USING EXPLAINABLE AI AND SATELLITE DATA: A RANDOM FOREST AND SHAP-BASED APPROACH

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ABSTRACT
Forest fires constitute a tremendous threat to the ecological system, public life, and economic resources. The only option to respond in time is accurate detection and real-time prediction of the same. The present paper proposes the utilization of machine learning-based method for predicting forest fire hazard with the assistance of satellite image of Earthdata of NASA. The research utilizes the Random Forest model for precise predictions and SHapley Additive exPlanations (SHAP) to enhance the transparency and interpretability of the model. The data set has prominent characteristics like brightness, surface temperature (bright_t31), radiative power of fire (FRP), confidence value, and geographical coordinates. These were all suitably preprocessed by data cleansing, normalization, and feature extraction. The resulting model was greatly predictive with great coefficient of determination ($R^2 = 0.91$) and minimal Root Mean Squared Error (RMSE = 0.54), making it worthwhile for prediction. What is unique about this project is the focus on explainability. SHAP analysis has been employed to calculate the contribution of every feature towards model output so that there is more understanding of why some areas are more susceptible to fire. Visualizations like feature importance charts, pairwise correlation charts, and spatial charts also gave decision-making capability. The results indicate surface brightness and temperature as the best predictors of fire danger. The explainable model can serve as an effective tool in the hands of forest management authorities, emergency services, and environmental monitoring organizations. Beyond its technical relevance, the project is suggestive of a scalable and adaptive solution that can be upscaled geographically and incorporated within real-time monitoring systems.
Keywords: Forest Fires, Machine Learning, Random Forest, Explainable AI, SHAP, Satellite Data, Predictive Modeling, Environmental Monitoring

1. Introduction

Wildfires are among the most devastating natural disasters, affecting ecosystems, biodiversity, and human livelihoods on a global scale. Driven by climate variability, anthropogenic activity, and increasing temperature anomalies, forest fires are becoming more frequent and intense. Early detection and accurate prediction of fire-prone regions are crucial for effective prevention and management.

In the context of this research, satellite imagery—particularly from NASA's Earthdata platform—offers a valuable and high-resolution resource for fire monitoring. However, the complexity of the data requires robust modeling techniques to extract meaningful insights. To address this, we implement a Random Forest regression model to predict the fire radiative power (FRP), a measure of fire intensity, using key environmental features. Importantly, we go beyond traditional modeling by integrating Explainable AI techniques, specifically SHAP, to provide transparency into model behavior.

This dual approach not only ensures accurate predictions but also supports interpretability, which is essential for deploying AI in high-stakes environmental applications. The integration of SHAP values allows stakeholders to understand how input features contribute to model outcomes, which strengthens trust and enhances decision-making in fire risk assessment.

2. Methodology

The dataset was acquired from NASA's FIRMS (Fire Information for Resource Management System) and included observations of fire events globally. Each data point contained geographical coordinates (latitude and longitude), thermal observations such as brightness and bright_t31, a confidence score indicating detection reliability, and the FRP values representing fire intensity.

Initial preprocessing steps involved removing incomplete or noisy entries. Features were then normalized using the PowerTransformer method to reduce skewness and ensure homogeneity across scales. Feature selection was performed to focus the analysis on the most predictive variables: brightness, bright_t31, confidence, latitude, and longitude. These variables were selected based on correlation analysis and domain relevance.

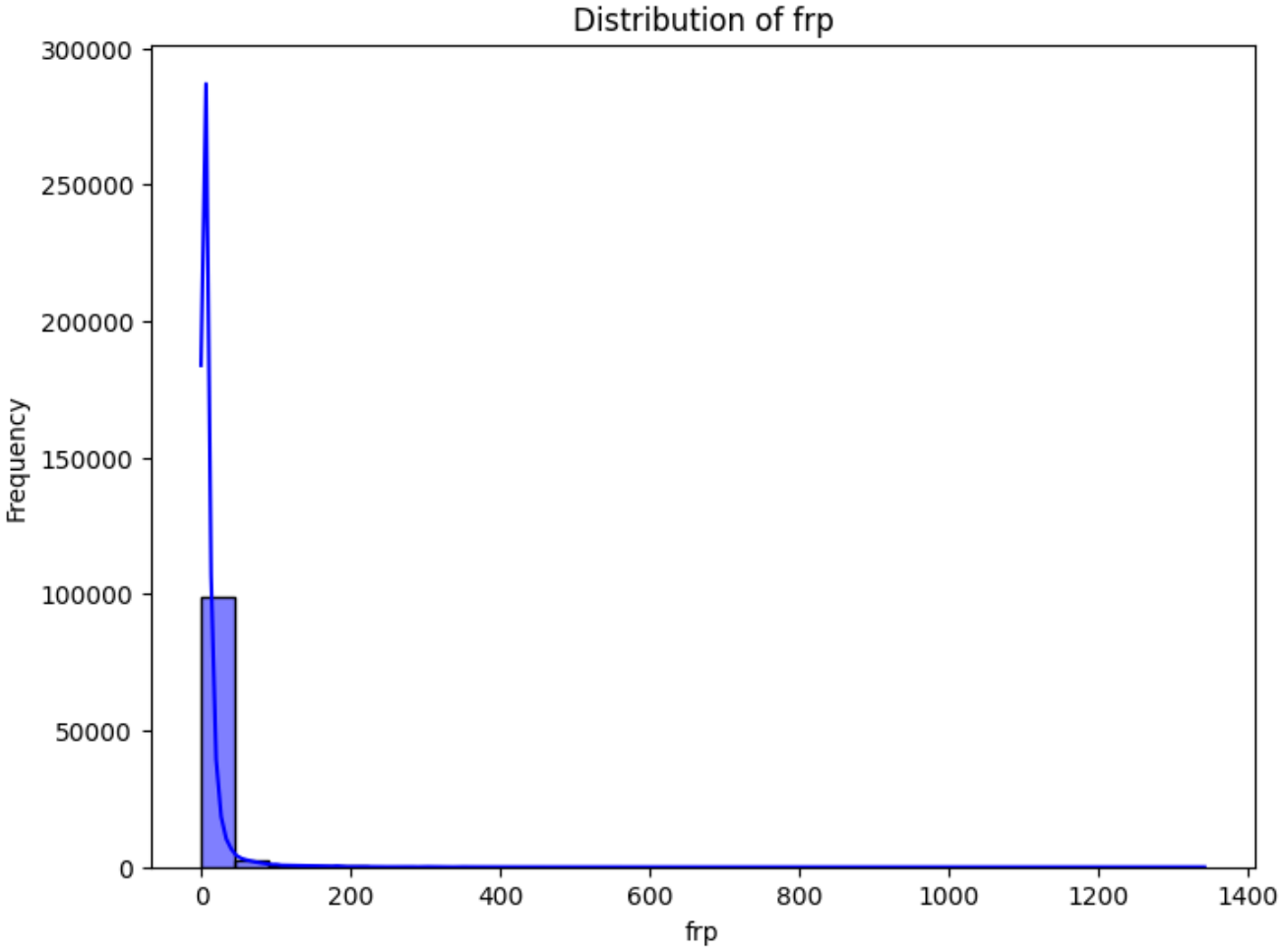
To ensure robustness, a 10-fold cross-validation strategy was implemented during training, providing a comprehensive evaluation of model generalizability. Hyperparameter tuning was conducted using randomized search to optimize the number of estimators, maximum tree depth, and other parameters of the Random Forest regressor. The model was assessed using both statistical metrics and visual inspection techniques, such as scatter plots comparing actual versus predicted values, to ensure the reliability of outputs.

A Random Forest regressor was trained to estimate FRP based on the preprocessed inputs. The model was evaluated using cross-validation, with performance assessed using R^2, RMSE, and visual comparisons between predicted and actual FRP values. To elucidate model decisions, SHAP analysis was applied, enabling quantification of each feature's contribution to individual predictions and overall model performance.

3. Results and Discussion

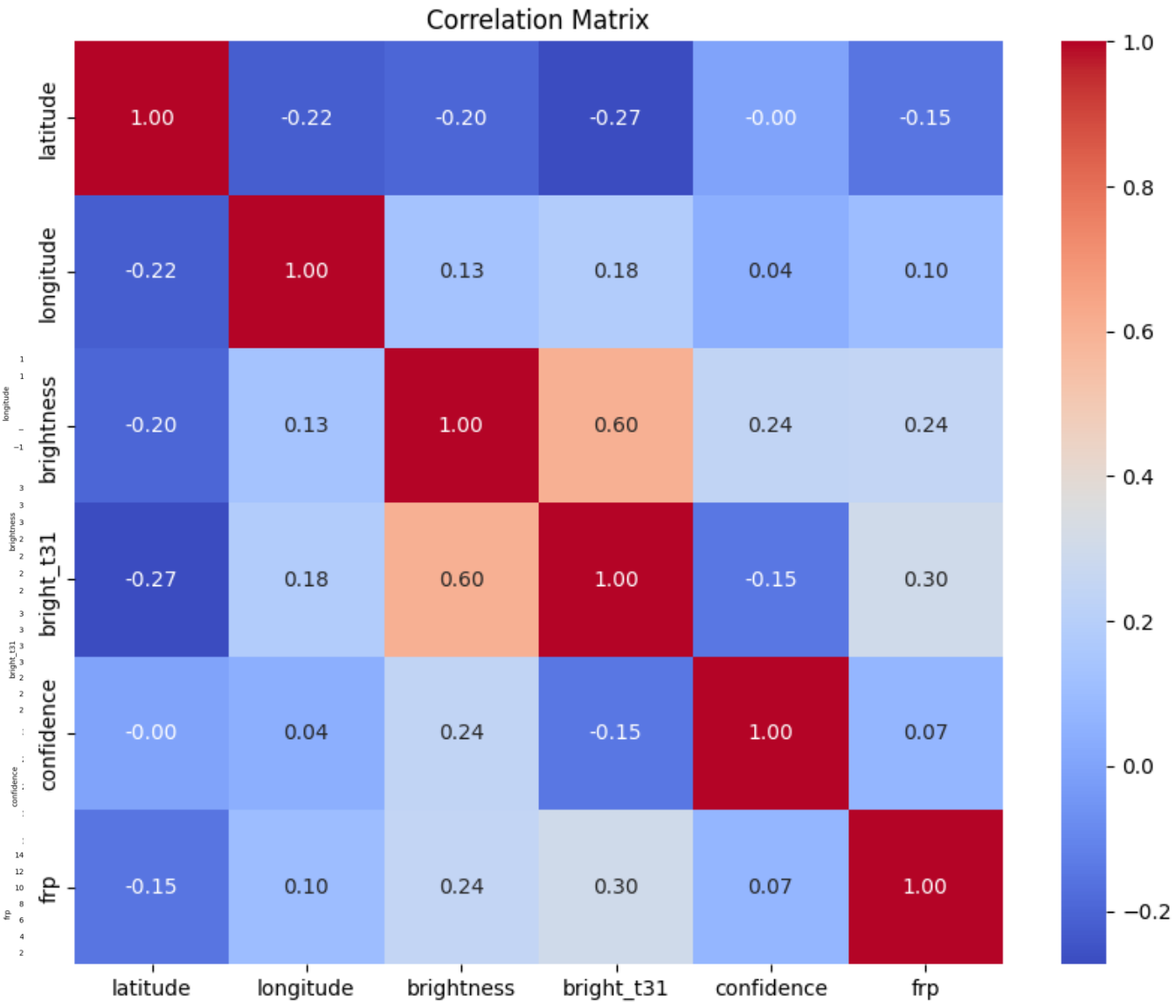
The initial analysis of the dataset showed a highly skewed distribution of fire radiative power values, with the majority of cases representing low-intensity fire events. This heavy concentration near the lower end of the scale highlighted the need for normalization techniques to

ensure robust model performance across the full range of observed fire intensities. The right-skewed distribution, if left uncorrected, could have led to biased model learning where predictions are disproportionately influenced by the dominant low-FRP instances. Additionally, such imbalance can hinder the model's sensitivity to more severe, high-risk fire events which are of significant ecological and operational interest. Therefore, the application of transformation techniques was critical for equalizing the influence of all fire intensity levels in the model training process.

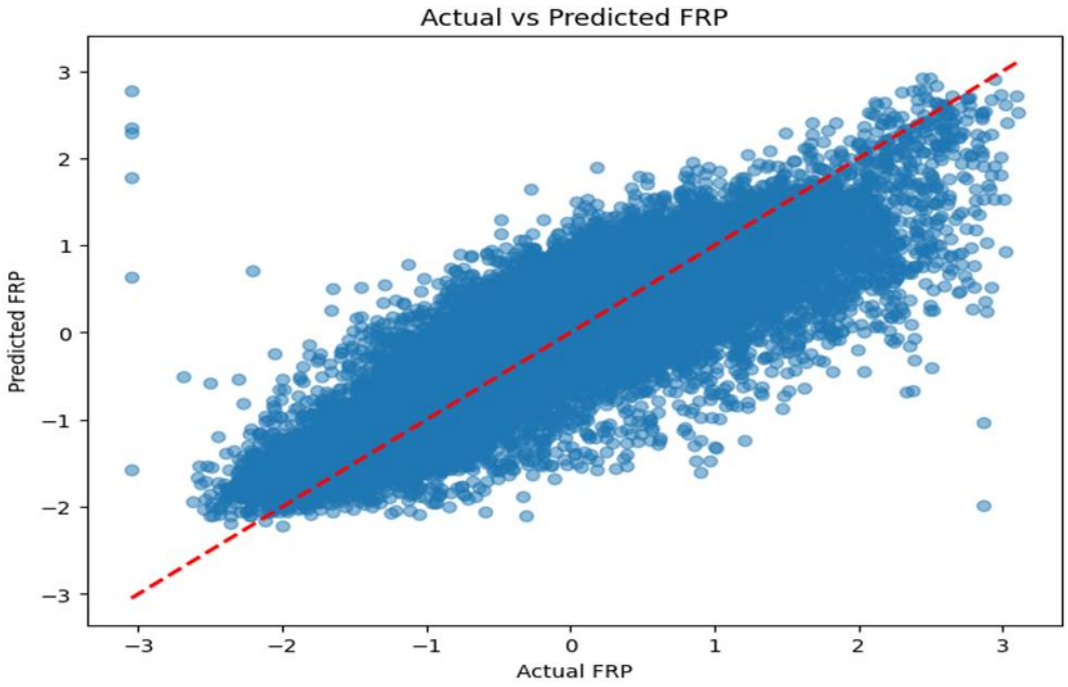


Furthermore, pairwise relationships among features revealed a strong positive interaction between brightness and surface temperature (bright_t31), underlining the combined relevance of thermal indicators in fire detection.

In terms of feature interdependencies, the correlation matrix reinforced these observations. This relationship reflects their shared sensitivity to thermal anomalies, which are often precursors to forest fires. Interestingly, the confidence level, despite being a common feature in fire datasets, exhibited relatively low correlation with FRP, indicating that it serves more as a detection quality indicator than a strong predictor of fire intensity.

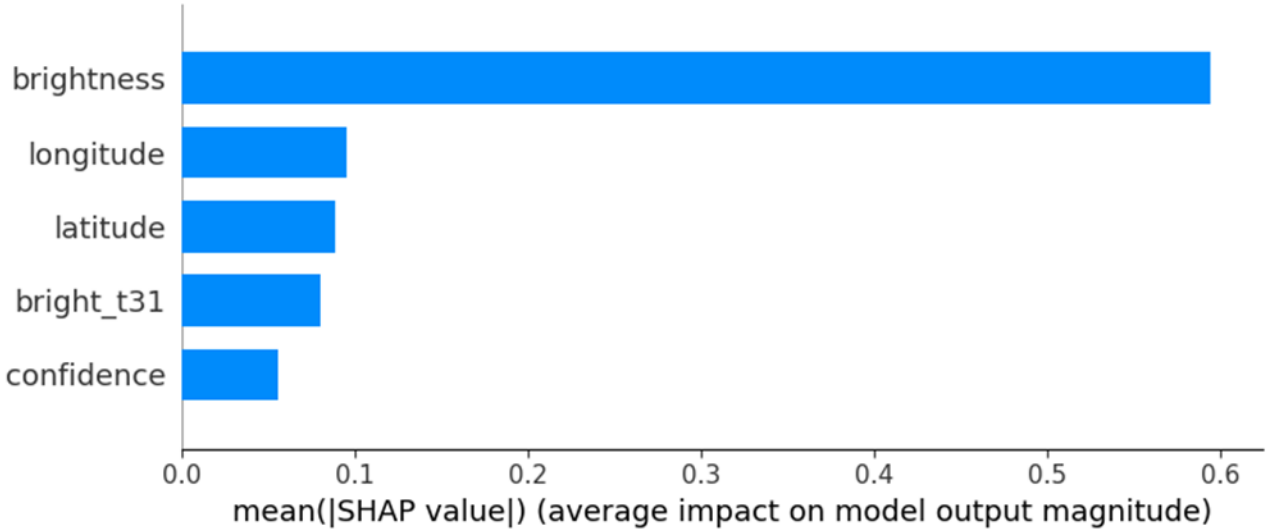


The performance of the Random Forest model proved highly satisfactory, with a coefficient of determination (R^2) of 0.91 and a root mean squared error (RMSE) of just 0.54. These metrics reflect the model's ability to generalize well across varied instances of fire intensity, capturing both the common and extreme events within the dataset. A scatter comparison of predicted versus actual FRP values supported this performance, showing a strong linear alignment with minimal dispersion, thereby confirming the model's precision across the spectrum of observed fire events. The low error margin also indicates that the model can serve as a practical forecasting tool in real-world applications, where early detection of even minor anomalies can prove vital in wildfire prevention efforts.



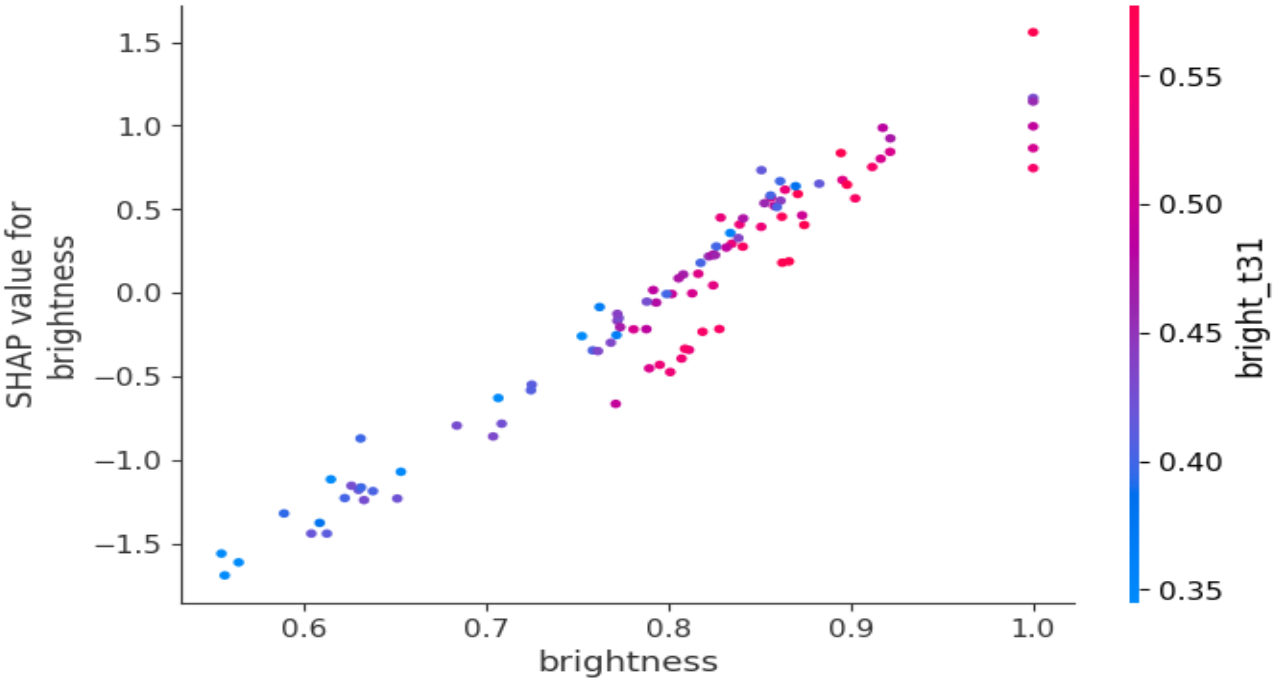
These results validate the model's ability to capture the underlying patterns in the dataset effectively and consistently.

A key contribution of this research lies in its application of SHAP analysis to interpret the model's behavior. The SHAP summary plot demonstrated that brightness was by far the most impactful feature in driving model predictions.



This ranking aligns with domain knowledge, as higher brightness typically correlates with intense thermal activity and thus stronger fire signals in satellite imagery.

The dependence of SHAP values on brightness confirmed a monotonic trend.



This effect was further contextualized by color-coded overlays based on bright_t31, which showed that areas with both high brightness and surface temperature exhibited the highest predicted fire intensities. Such visualizations enhance interpretability and provide actionable insights for fire risk management.

Altogether, the integration of performance metrics, inter-feature analysis, and SHAP-based explainability formed a comprehensive understanding of the factors driving fire intensity predictions. This multifaceted evaluation supports both scientific rigor and practical application, offering a model that is not only accurate but also interpretable and transparent.

4. Conclusion

This study confirms that forest fire intensity, measured via FRP, can be accurately predicted using satellite-derived thermal features through machine learning. The Random Forest model demonstrated excellent performance and generalizability. The integration of SHAP for model interpretability proved essential, highlighting brightness and surface temperature as key indicators of fire risk.

By offering both predictive accuracy and interpretability, the framework aligns with the goals of operational environmental monitoring. It empowers forest management authorities to identify high-risk areas, allocate resources proactively, and make informed decisions based on interpretable AI.

Future research may incorporate spatiotemporal dynamics and real-time prediction modules to improve scalability. Integrating additional meteorological factors such as wind speed or humidity could also enhance model fidelity. Nonetheless, this work lays a solid foundation for transparent, data-driven fire risk prediction.

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PREDICTING STUDENT MENTAL HEALTH USING MACHINE AND DEEP LEARNING APPROACHES

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ABSTRACT
The research in this article investigates the application of Machine Learning (ML) and Deep Learning (DL) algorithms in predicting mental illness in students based on a combination of psychological, academic, and demographic data. Since mental illness has gradually become increasingly prevalent among students and has begun to encroach on their academe and well-being, its detection has become significant to institutions and schools. In this study, comparative analysis is conducted by implementing and cross-validating various forecasting models including Random Forest, XGBoost, Gradient Boosting, and Neural Networks on a dataset of anonymous online survey data. Data collected provide an insight into the level of stress among students, social life, age group, and study workload. A preprocessing strategy of data in tabular form was employed to ensure quality data and ready the models. Categorical variable encoding and missing value imputation were performed with the appropriate statistical measures. Models were also tried on different evaluation metrics in a bid to have a clear view of how they performed towards mental health condition prediction. Ensemble models had good and stable predictive abilities, and neural networks showed promise in revealing subtle, non-linear patterns in the data. This study is unique in comparing the ML and DL models alongside each other on the same dataset from which direct comparison of model performance on student mental health is possible. This composite research makes the study stand out from existing research where there has been a favorite modeling technique over the other. The research reveals predictive modeling as a promising tool in the creation of early warning systems and in facilitating schools and educational institutions to provide timely, personalized psychological intervention. This constructs improved academic environment and overall success of the learner.
Keywords: Mental Health Prediction, Machine Learning, Deep Learning, Student Well-being, Neural Networks, Educational Data Mining, Early Intervention, Psychological Support.

1. Introduction

Mental health among students has emerged as a crucial area of concern for educators and policymakers worldwide. Academic pressures, social isolation, and personal expectations are increasingly affecting students' emotional and psychological well-being. Numerous studies have shown that mental health disorders such as stress, anxiety, and depression can negatively influence academic performance and social development. Despite growing awareness, early detection of mental health issues remains a challenge, especially due to the stigmatization surrounding psychological support and the lack of scalable, proactive monitoring systems.

In recent years, data-driven technologies have demonstrated significant potential in identifying early signs of mental health deterioration. Machine Learning (ML) and Deep Learning (DL) approaches can analyze complex patterns in student data to make accurate predictions and classifications. Algorithms like Random Forest (Breiman, 2001), XGBoost (Chen & Guestrin, 2016), and neural networks (Goodfellow et al., 2016) are well-suited to detect subtle relationships between variables, which can be instrumental in mental health forecasting.

This study aims to compare the predictive performance of multiple ML and DL models on the same student dataset. By exploring a unified framework that evaluates Random Forest, Gradient Boosting, XGBoost, and Neural Network models, the study contributes to the development of robust early-warning systems that can guide targeted psychological interventions. The research fills a gap by offering a transparent comparative analysis rather than promoting a single technique, thereby providing valuable insights for data scientists, psychologists, and educational institutions.

2. Methodology

The research followed a structured methodology that began with the design of an anonymous survey using Google Forms to collect relevant data from university and high school students. The survey aimed to capture variables associated with mental health, including students' age group, levels of daily stress, social interaction quality, and academic workload.

To ensure the quality of data for modeling, several preprocessing steps were performed. Categorical variables were converted into numerical format using label encoding, and missing values in the dataset were imputed using the median of the respective attributes. Since the dataset exhibited class imbalance, the Synthetic Minority Oversampling Technique (SMOTE) was applied to augment minority class instances, enabling more balanced and fair model training.

The core of the analysis involved the implementation of four predictive models: Random Forest, Gradient Boosting, XGBoost, and a Neural Network. These models were evaluated using cross-validation to ensure robust and generalized results. Model performance was assessed based on Accuracy, F1 Score, and Receiver Operating Characteristic Area Under the Curve (ROC AUC). These metrics provided a comprehensive evaluation of the models' ability to classify mental health status effectively.

3. Results and Discussion

This section presents the evaluation outcomes of the machine learning and deep learning models used to predict student mental health conditions. The analysis aims to identify which algorithms offer the best trade-off between predictive accuracy and generalizability. By comparing key performance indicators across models, we gain insights into their relative strengths and limitations when applied to educational psychological data. The dataset provided a mix of categorical and numerical variables that were processed and standardized to optimize model performance. The cross-validation strategy enabled a fair comparison of model robustness and

ensured that the results were not biased toward a specific training subset. Each model was fine-tuned using grid search methods to find the best combination of hyperparameters. Moreover, evaluation was not limited to accuracy; metrics like F1 Score and ROC AUC were included to provide a balanced view of each model's ability to generalize, especially under class imbalance conditions.

The comparative results of the predictive models are summarized below:

Model	**Accuracy (%)**	**ROC AUC (%)**	**F1 Score (%)**
Random Forest	76.7	94.6	76.2
XGBoost	75.8	91.2	75.2
Gradient Boosting	70.8	89.7	70.3
Neural Network	70.8	89.7	68.7

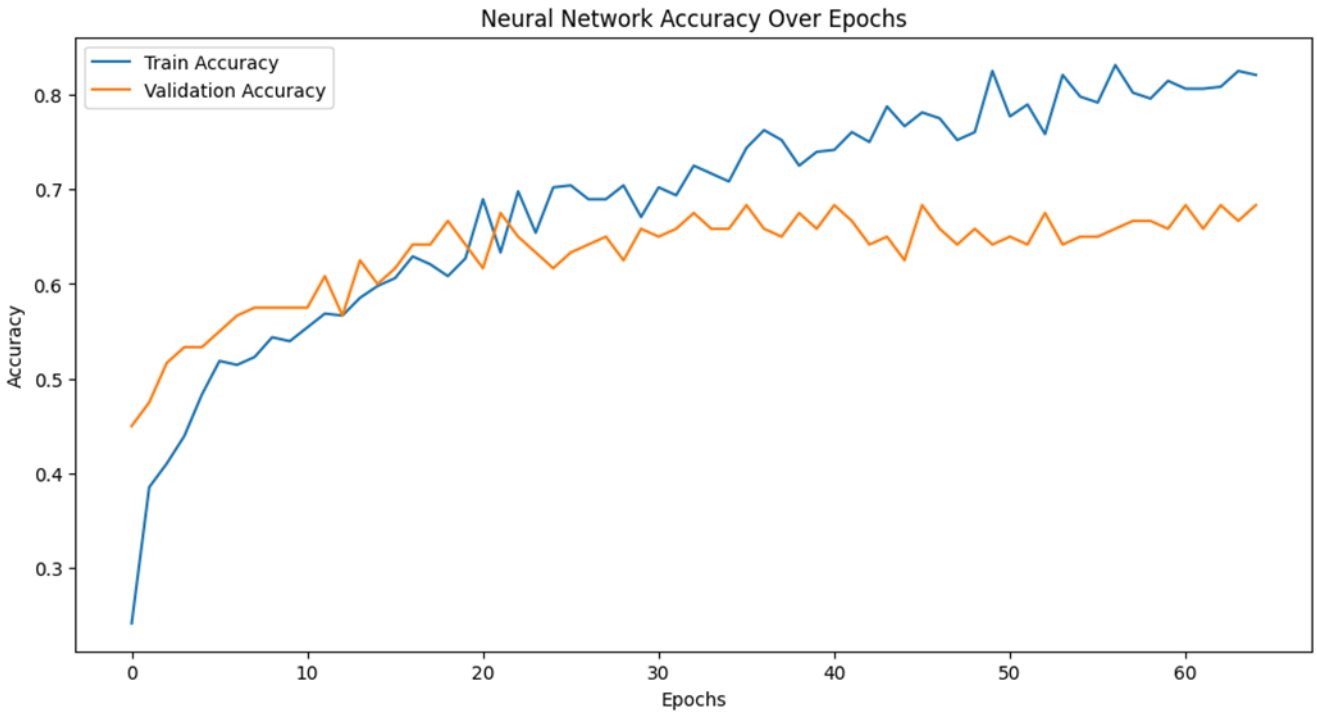

Figure 1: Neural Network Accuracy Over Epochs

This graph (Figure 1) illustrates how the neural network model's training accuracy consistently improves over epochs, while validation accuracy stabilizes, indicating potential overfitting.

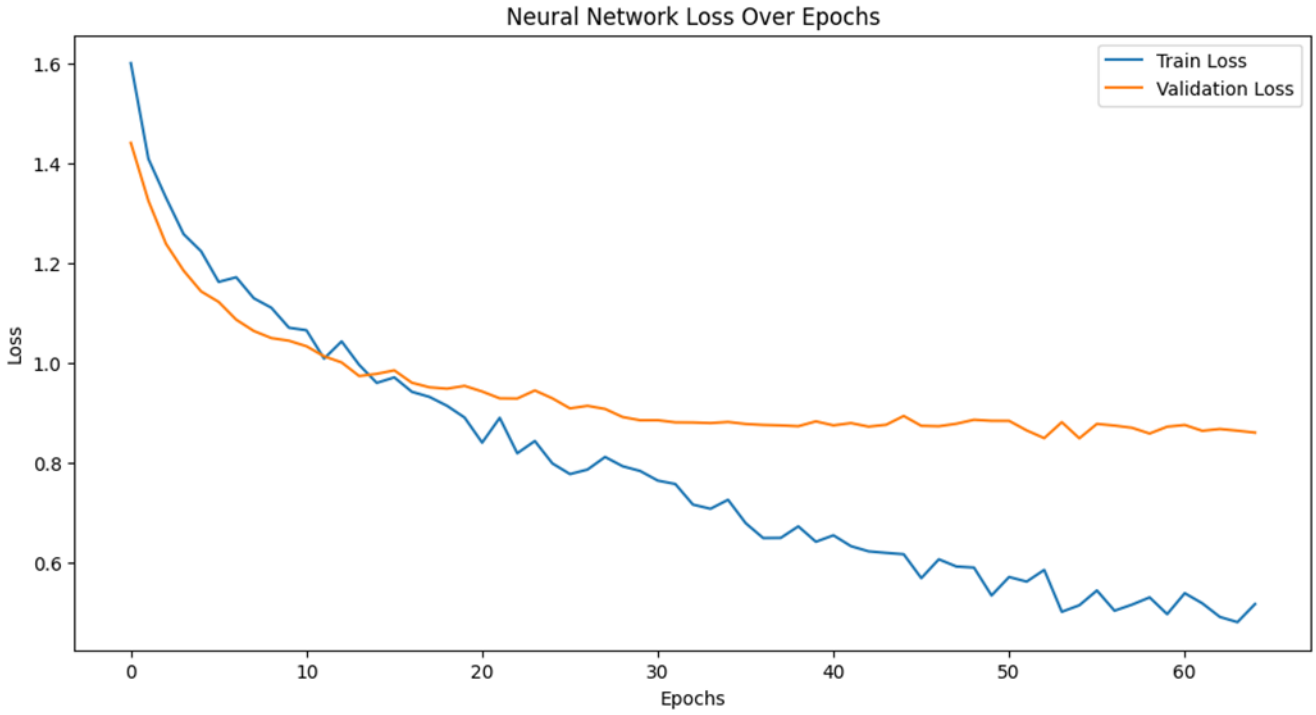

Figure 2: Neural Network Loss Over Epochs

On the other hand, Figure 2 shows the decreasing trend of training and validation loss, confirming effective learning in the early stages and highlighting divergence as a sign of overfitting.

The Random Forest model outperformed other algorithms in all three metrics, achieving an accuracy of 76.7% and an impressive ROC AUC score of 94.6%. This result highlights the model's strength in capturing complex feature interactions while maintaining generalizability, making it particularly suitable for datasets with mixed feature types and varying importance levels. Additionally, the model showed resilience to noise and overfitting, which is beneficial in real-world educational data where some inputs may be inconsistent or incomplete. XGBoost, another tree-based ensemble model, closely followed with consistent performance metrics, showcasing its known ability to handle sparse data and regularization effectively.

Gradient Boosting and Neural Networks also performed reasonably well, though they slightly lagged in terms of F1 Score and Accuracy. Gradient Boosting showed a balanced performance but was limited by its sensitivity to noisy data and requirement for careful hyperparameter tuning. The Neural Network achieved a promising ROC AUC of 89.7%, indicating a strong capability to distinguish between classes, thanks to its ability to learn intricate, non-linear patterns in the data. However, the model's performance was constrained by the relatively small dataset size, which likely contributed to overfitting as depicted in Figures 1 and 2. Specifically, the training accuracy continued to rise steadily while the validation accuracy plateaued and fluctuated after a certain epoch, reflecting the model's decreasing generalization ability.

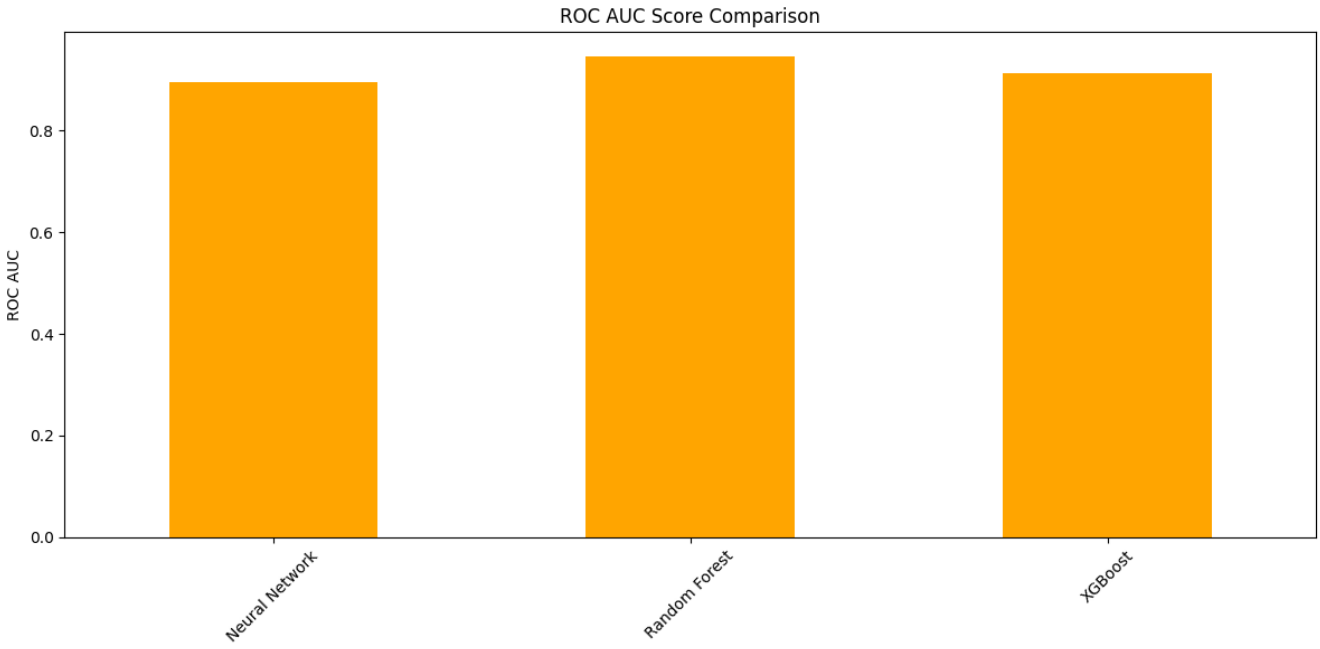

Figure 3: ROC AUC Score Comparison Across Models

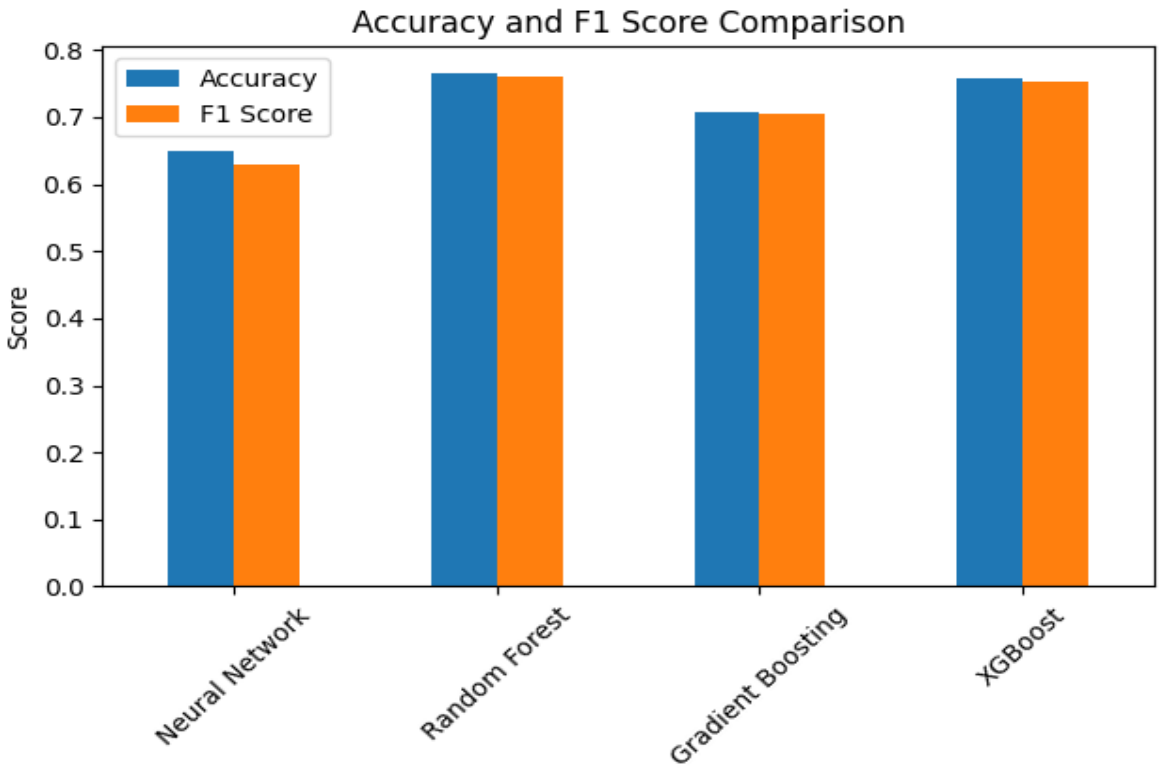

Figure 4: Accuracy and F1 Score Comparison

Figures 3 and 4 offer a visual perspective on model comparisons, clearly showing Random Forest's lead. These graphical results enhance interpretability and assist stakeholders in selecting appropriate models for future early-intervention systems in educational settings.

4. Conclusion

This research demonstrates the effectiveness of combining machine and deep learning methods to predict student mental health conditions using survey-based features. Among the evaluated models, Random Forest provided the most reliable and balanced predictions, followed closely by XGBoost. These ensemble-based techniques are particularly valuable due to their robustness to overfitting and ability to handle heterogeneous feature sets.

Although Neural Networks displayed lower accuracy, their high ROC AUC suggests latent potential in modeling non-linear relationships within the data. Their performance could be enhanced with larger datasets and more advanced architectures. Gradient Boosting showed adequate results but underperformed compared to other methods.

The comparative approach presented in this study offers a unique contribution by evaluating all models under the same experimental conditions. Educational institutions can leverage such data-driven methods to develop early warning systems and offer timely psychological support to at-risk students. In future work, the incorporation of longitudinal data, feature selection techniques, and explainable AI components may further improve the accuracy and interpretability of such models.

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DARK SKY: ENGINEERING THE FUTURE OF LIGHT WITH SUSTAINABILITY IN MIND

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ABSTRACT

Light pollution is an increasingly pervasive and often underestimated environmental issue. This paper explores the philosophy and practices of the Dark Sky movement, an initiative grounded in scientific evidence and ethical design, aimed at reducing the adverse effects of artificial light at night (ALAN). The abstract summarizes key concepts: the different types of light pollution, their environmental and health consequences, and the technological and regulatory strategies proposed to mitigate these impacts. As urbanization expands and artificial illumination becomes ubiquitous, the disruption of natural cycles from wildlife migration to human circadian rhythms presents serious consequences for ecological balance and public health. Technologies such as full cut-off luminaires, warm-spectrum LEDs, and adaptive lighting controls are proposed solutions that not only conserve energy but also minimize skyglow and light trespass. Additionally, the paper highlights the growing cultural and economic value of preserving natural nightscapes through initiatives like astrotourism. Drawing on resources and data from the International Dark-Sky Association (IDA), the paper reinforces the need for an interdisciplinary approach that blends engineering, urban planning, environmental science, and community education. The preservation of the night sky is not simply a nostalgic ideal; it is an actionable imperative rooted in sustainability, biodiversity protection, and human wellness. This paper concludes that responsible lighting design is a symbol of ethical progress one that illuminates not just our paths, but our values.

Introduction - The Problem Hidden in Plain Sight

In an age where cities shine brighter than the stars themselves, artificial lighting has become both a symbol of modernity and a source of environmental harm. The widespread and often excessive use of artificial light at night has led to a phenomenon known as light pollution. According to the International Dark-Sky Association (IDA), light pollution is defined as "the inappropriate or excessive use of artificial light," which includes glare, skyglow, light trespass, and clutter (IDA, 2024). These effects go beyond mere aesthetic degradation of the night sky they have measurable impacts on wildlife, ecosystems, human health, and energy consumption.

The origins of light pollution are linked to rapid urbanization, increased commercial development, and the unregulated expansion of lighting infrastructure. Street lamps, building floodlights, illuminated advertisements, and residential lighting often emit light in inefficient directions, including upward toward the sky, causing skyglow that obscures astronomical visibility. More than 80% of the world's population lives under light-polluted skies, with that figure rising to over 99% in the United States and Europe (IDA, 2024).

The Dark Sky movement was established in response to this growing concern. Advocating for lighting practices that are environmentally sensitive, scientifically informed, and human-centered, this global effort seeks to restore the natural darkness of the night sky. This paper explores how sustainable lighting design emphasizing proper fixture design, reduced blue light emissions, and smart lighting controls can address the multifaceted consequences of light pollution. It also highlights how public policy and international guidelines are critical in shaping future cityscapes that are both functional and environmentally responsible.

Development - A Deeper Understanding of Light Pollution's Reach

Light pollution is not a single phenomenon but a constellation of interrelated problems:

- **Glare** blinds drivers and pedestrians, reducing safety.
- **Skyglow** robs cities of their celestial visibility.
- **Light trespass** invades homes and habitats.
- **Clutter** overwhelms visual environments with excess brightness.

Each of these disrupts ecological integrity. Nocturnal animals, whose survival is calibrated to lunar cycles and starlight, suffer behavioral chaos when nights are artificially extended. Birds crash into illuminated buildings during migration.

Sea turtle hatchlings crawl toward parking lots instead of moonlit oceans. Plants bloom off-season, altering entire ecosystems.

Humans, too, suffer from this artificial extension of daylight. Exposure to blue-rich light especially from LEDs suppresses **melatonin** secretion, a hormone critical for regulating sleep, mood, metabolism, and even immunity. The World Health Organization has linked circadian disruption to chronic diseases, including certain cancers (IDA, 2024).

Moreover, light pollution represents an enormous **waste of energy**. It is estimated that nearly **30% of outdoor lighting in the U.S. alone is wasted**, equating to over $3 billion annually (IDA, 2024). In contrast, municipalities that adopt Dark Sky-compliant systems often see a return on investment through reduced energy bills and increased **astrotourism**, a growing niche that proves darkness has both ecological and economic value.

Fortunately, we are not powerless in the face of this illuminated dilemma. Several **design and policy strategies** offer tangible results:

1. **Full cut-off luminaires** direct light downward, eliminating upward and sideways spill.
2. **Warm-spectrum LEDs** (ideally 2200K–2700K) minimize disruptive blue wavelengths.
3. **Smart lighting systems** adjust output based on time, motion, and activity levels.
4. **Lighting curfews and lumen limits** establish enforceable boundaries for nighttime lighting.

These interventions are most effective when applied holistically. For instance, a park may use amber LEDs at low mounting heights and motion sensors that dim lights when no one is present. Urban planners can design neighborhoods where lighting levels follow local biodiversity needs.

Perhaps most crucial is **public awareness and education**. A well-informed citizenry is more likely to support regulations and adjust personal behaviors. The success of the Dark Sky movement hinges not only on technical innovation, but on a shared cultural shift one that celebrates the night not as a void, but as a vital part of Earth's rhythm.

Conclusion - Lighting the Right Way

The Dark Sky movement is a vital response to a problem often hidden in plain sight. Light pollution is not a byproduct of progress; it is a design flaw one that can be corrected with intention, knowledge, and ethical commitment. As explored in this paper, artificial light at night interferes with natural biological systems, threatens biodiversity, wastes energy, and diminishes cultural and astronomical heritage. Fortunately, the tools to mitigate this crisis are already within reach. Full cut-off fixtures, warm-spectrum LEDs, and adaptive lighting systems provide both functionality and ecological sensitivity. Just as important are the policies and educational initiatives that shape how societies understand and manage their nighttime environments.

Public engagement is essential. Campaigns that raise awareness, encourage community participation, and integrate lighting best practices into urban planning are critical for long-term success. Dark Sky International and other advocacy organizations provide valuable resources and guidelines that municipalities can adopt to align their lighting strategies with sustainability goals. Astrotourism, once a niche interest, has demonstrated that darkness can be economically and culturally valuable.

Ultimately, this issue is not about turning off the lights it is about turning on the right kind of light. It is about shifting the narrative: from brightness as progress to balance as progress. In doing so, we not only preserve ecosystems and save energy, but we also rekindle humanity's relationship with the stars. The future of urban lighting is not measured in lumens, but in wisdom.

By engineering light responsibly, we illuminate our values as much as our spaces. Ultimately, the future is not about extinguishing light. It is about **illuminating wisely**. We must shift our understanding of progress from brightness to balance, from dominance to coexistence. When we light with care, we don't just see better we live better.

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INVESTIGATION OF CONTACT CORROSION BETWEEN ALUMINUM HINGES AND STEEL BODY IN COMMERCIAL VEHICLES USING DIFFERENT PROTECTION METHODS

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ABSTRACT
In this study, contact corrosion that may occur as a result of galvanic contact between aluminium hinges used in commercial vehicles and steel vehicle body was investigated using different protection methods. Within the scope of the study, the hinge bodies are made of 6082 T6 aluminium, the plates where the hinges are connected to the vehicle body are made of HX380LAD+Z (Z140) galvanised steel and the plates on the door side are made of 5182 aluminium. As a protection method, SurTec 650, cataphoresis coating and uncoated options were applied to the hinge surfaces. In addition, interface solutions such as Teroson RB81, Superlite Green Seal and Superlite Green Seal + additional sheet metal plate were placed between the hinge and plate materials to reduce galvanic interaction. The specimens were subjected to salt fog test to evaluate the formation of white rust for 96 hours and red rust for 360 hours in accordance with ASTM B117 standards. After the test, the samples were analysed by visual inspection and mass loss method. According to the results obtained, SurTec 650 and cataphoresis coated hinges showed high corrosion resistance. However, the cataphoresis-coated specimen was tested without mounting with the vehicle body and door plate. The uncoated hinge specimens performed poorly and failed the corrosion tests. The interconnection materials made a limited contribution to the reduction of contact corrosion, especially the surface coatings were found to be decisive on the protection performance.
Keywords: Galvanic Corrosion, Aluminum-Steel Contact, Surface Treatment, Salt Spray Test, Commercial Vehicle Hinges, Contact Corrosion

1. Giriş

Günümüzde otomotiv endüstrisi, hafiflik ve dayanımın birlikte sağlanması amacıyla çoklu malzeme kullanımını giderek daha fazla benimsemektedir. Özellikle ticari araçlarda, gövde ağırlığını azaltmak amacıyla çelik yapı elemanlarıyla birlikte alüminyum parçaların kullanımı yaygınlaşmaya başlamıştır. Bu yapıların montajında ortaya çıkan galvanik temas, özellikle dış ortam koşullarında korozyon riskini artırmaktadır. Galvanik korozyon, farklı elektrokimyasal potansiyele sahip metallerin elektrolit ortamında bir araya gelmesiyle meydana gelir ve temas eden yüzeylerde korozyona neden olabilir [1].

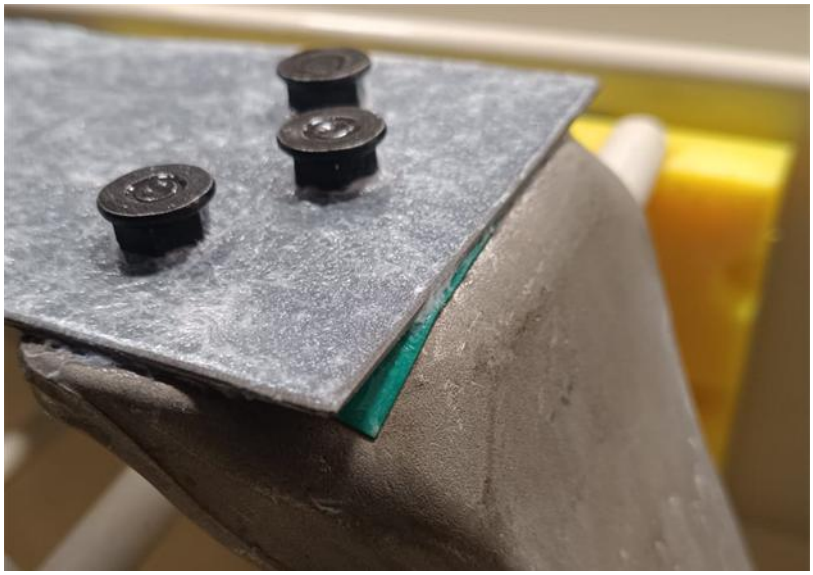
Bu çalışmada, 6082 T6 alüminyumdan üretilmiş ticari araç menteşeleri ile HX380LAD+Z (Z140) galvanizli çelik araç gövdesi sacı ve 5182 alüminyum kapı sacı arasındaki temas bölgelerinde oluşabilecek kontak korozyonu, farklı yüzey kaplama ve arayüz çözümleri ile değerlendirilmektedir. Özellikle menteşe bölgelerinde yüzey kaplamalarının ve araya yerleştirilen sızdırmazlık malzemelerinin galvanik korozyon üzerindeki etkisi incelenmiştir.

Yapılan literatür araştırmalarında, benzer malzeme çiftlerinde görülen galvanik korozyonun, uygun yüzey kaplamaları ve izolatör malzeme kullanımı ile önemli ölçüde azaltılabildiği belirtilmektedir [2]. Özellikle SurTec 650 ve kataforez (KTL) gibi kaplama yöntemlerinin, alüminyum parçaların çelik yapılarla temas ettiği bölgelerde etkin koruma sağladığı rapor edilmiştir. Bununla birlikte, kaplamasız alüminyum ve galvanizli çelik temas bölgelerinde, NTS (Natural Salt Sprey) koşulları altında erken korozyon başlangıçları gözlemlenmiştir.

Çalışmanın amacı, ticari araçlarda kullanılan alüminyum menteşelerin çelik ve alüminyum gövde sacları ile montajlandığı durumlarda, farklı koruma yöntemlerinin galvanik korozyona karşı etkinliğini deneysel olarak değerlendirmektir.

Malzeme	**Kullanım Yeri**	**Ana Alaşım Elementleri**	**Standart / Kalite**	**Kalınlık (mm)**	**Özellikler**
6082 T6 Alüminyum	Menteşe gövdesi	Al – Mg – Si	EN AW-6082 / T6	-	Yüksek mukavemet, iyi korozyon direnci
5182 Alüminyum	Kapı iç sacı	Al – Mg	EN AW-5182	1 mm	İyi şekillenebilirlik, orta mukavemet
HX380LAD+Z	Araç gövdesi sacı	Düşük karbonlu çelik + Zn kaplama	EN 10346 - Yüksek dayanım IF çelik	2 mm	Yüksek dayanım, galvaniz kaplama ile koruma

Tablo 1. Kullanılan malzeme özellikleri ve kimyasal bileşimleri.



Şekil 1 Alüminyum menteşe ve çelik gövde bağlantısının şematik gösterimi.

2. Materyal ve Metod

Bu çalışmada, ticari araçlarda kullanılan alüminyum menteşelerin, çelik ve alüminyum gövde sacları ile montajlandığı bölgelerde oluşabilecek galvanik korozyon, farklı yüzey kaplama ve arayüz izolasyon yöntemleri ile incelenmiştir. Çalışma deneysel olarak gerçekleştirilmiş olup, numuneler ASTM B117 standardına uygun olarak tuz sisi testine tabi tutulmuştur.

2.1 Kullanılan Malzemeler

Deneylerde kullanılan menteşe gövdesi malzemesi, 6082 T6 alüminyum alaşımıdır. Menteşelerin bağlandığı araç gövdesi plakaları HX380LAD+Z (Z140 galvanizli) çelikten, kapı gövdesine karşılık gelen plakalar ise 5182 serisi 1 mm kalınlığında alüminyumdan kesilmiştir.

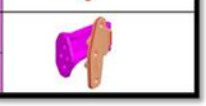
2.2 Kaplama ve İzolasyon Yöntemleri

Deney numunelerinde kullanılan menteşelere üç farklı yüzey işlemi uygulanmıştır:

- **SurTec 650** kaplaması (kromat kaplama)
- **Kataforez (KTL)** kaplaması
- **Kaplamasız (ham alüminyum)**

Menteşe bağlantılarında galvanik korozyonu önlemek amacıyla üç farklı arayüz çözümü kullanılmıştır:

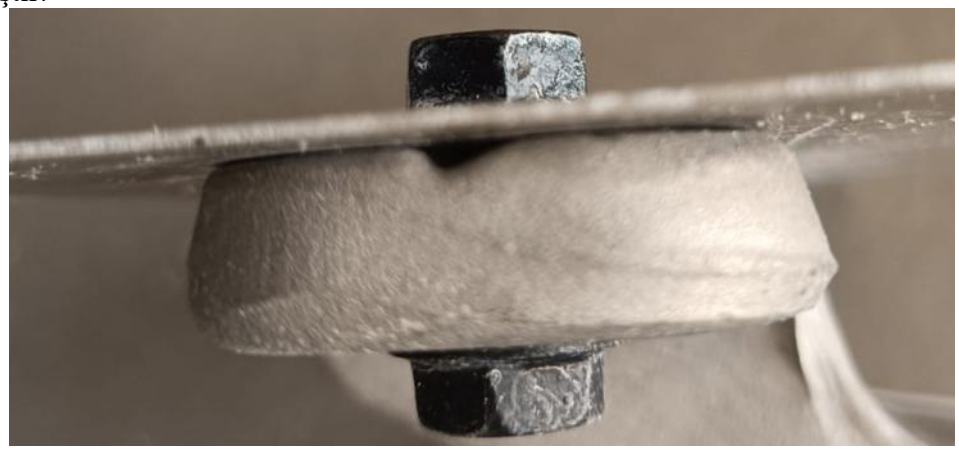
- **Teroson RB81** contalama uygulaması
- **Superlite Green Seal** sızdırmazlık malzemesi
- **Superlite Green Seal + ek sac plaka** (yalıtım levhası takviyesi)

	PARÇA	KAPLAMA	SEAL	EKSTRA PARÇA PLAKA	MONTAJ DURUMU	GÖRSEL
1	ÜST MOBİLE	SURTEK	YOK	YOK	MONTAJLI	
	ÜST FİX	SURTEK	YOK	YOK		
2	ÜST FİX	SURTEK	Super lite	YOK	MONTAJLI	
	ÜST MOBİLE	SURTEK		YOK		
3	ÜST FİX	SURTEK	TERESON RB81	YOK	MONTAJLI	
	ÜST MOBİLE	SURTEK		YOK		
4	ÜST FİX	YOK	Super lite	YOK	MONTAJLI	
	ÜST MOBİLE	YOK		YOK		
5	ÜST FİX	SURTEK	Super lite	SAC PLAKA	MONTAJLI	
	ÜST MOBİLE	SURTEK		SAC PLAKA		
6	ÜST FİX	YOK	Super lite	SAC PLAKA	MONTAJLI	
	ÜST MOBİLE	YOK		SAC PLAKA		
7	ÜST FİX	SURTEK	YOK	YOK	SOLO PART	
	ÜST MOBİLE	SURTEK	YOK	YOK	SOLO PART	
8	ÜST FİX	YOK	YOK	YOK	SOLO PART	
	ÜST MOBİLE	YOK	YOK	YOK	SOLO PART	

Tablo 2. Uygulanan Koruma Yöntemleri ve Numune Grupları

2.3 Montaj ve Numune Hazırlığı

Her bir numune, menteşe ile çelik ve/veya alüminyum plakanın somun ve cıvata ile sabitlenmesiyle oluşturulmuştur. Gerçek araç montaj koşullarına benzer şekilde oluşturulan birleşimler, galvanik temasa uygun olacak şekilde sıkıştırılmış ve montaj yüzeyleri önceden temizlenmiştir.



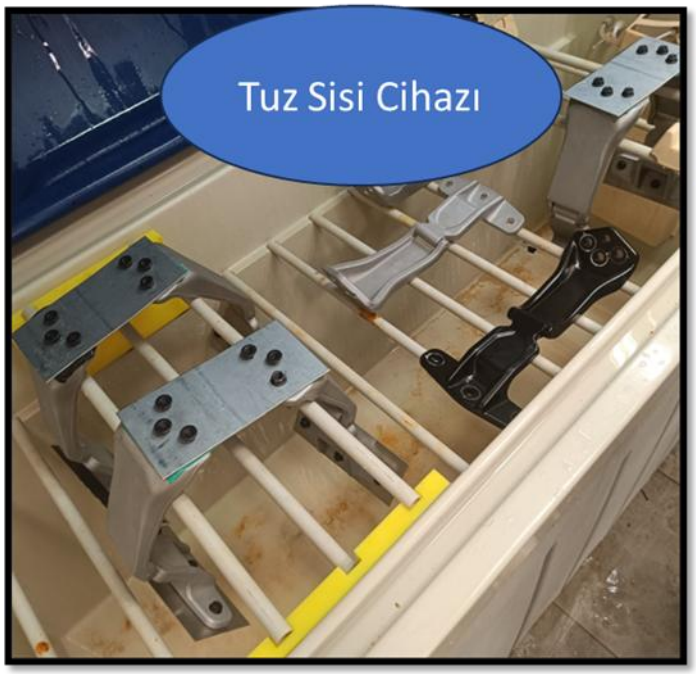
Şekil 2. *Numune Bağlantı Detaylarının Şematik Gösterimi*

2.4 Tuz Sisi Testi (Salt Spray Test)

Numuneler, ASTM B117 standardına uygun olarak 96 saat tuz sisi testine tabi tutulmuştur. Test kabininde ortam sıcaklığı 35 ± 2 °C, pH değeri 6.5 – 7.2 arasında olan %5 NaCl çözeltisi sürekli olarak püskürtülmüştür.

Test değerlendirmesi, aşağıdaki kriterlere göre yapılmıştır:

- **96 saatte beyaz pas oluşumu**
- **360 saatte kırmızı pas oluşumu**



Görsel 2. Tuz Sisi Test Kabini ve Numune Yerleşim Düzeni

2.5 Değerlendirme Yöntemleri

Tuz sisi testinin sonunda numuneler iki farklı yöntemle değerlendirilmiştir:

1. **Görsel İnceleme**: Pas oluşumu, yüzey bozulmaları ve koruma performansı çıplak gözle ve büyüteç ile incelenmiştir.
2. **Kütle Kaybı Analizi**: Test öncesi ve sonrası ölçülen kütle farkı ile korozyonun malzeme üzerindeki etkisi kantitatif olarak değerlendirilmiştir.

SONUÇLAR

Bu çalışmada, farklı yüzey kaplama ve ara katman koruma yöntemlerinin alüminyum menteşe ile çelik araç gövdesi arasındaki kontak korozyonuna etkisi, tuz sisi testi (ASTM B117) ile sistematik olarak değerlendirilmiştir. Toplamda sekiz farklı kombinasyon incelenmiş ve hem görsel inceleme hem de kütle kaybı ölçümleri üzerinden performans karşılaştırmaları yapılmıştır. Test sonuçları aşağıdaki şekilde özetlenebilir:

- **SurTec 650 ile yüzey işlem görmüş menteşeler**, tüm ara katman uygulamaları ile birlikte kullanıldığında hem **beyaz pas hem de kırmızı pas oluşumunu engellemiş** ve minimum kütle kaybı ile başarılı sonuçlar vermiştir. Bu yapıların ortalama kütle kaybı 5 mg altında kalmıştır.
- **Kaplamasız menteşeler**, ara katman uygulanmış olsa dahi özellikle 360 saatlik test süresi sonunda **kırmızı pas oluşumuna maruz kalmış** ve gözle görülür kütle kaybı sergilemiştir. Bu örneklerde ortalama kütle kaybı 17–21 mg aralığında ölçülmüş olup, **korozyon direnci açısından başarısız** olarak değerlendirilmiştir.
- **Katoforez kaplamalı menteşe**, diğerlerinden farklı olarak gövde ve kapı ile montajlı değil, tekil halde test edilmiştir. Buna rağmen hem görsel hem de kütle kaybı açısından en iyi sonucu vermiştir. Ancak montajlı test koşullarında performans tekrar doğrulanmalıdır.

- Ara katman olarak kullanılan **Teroson RB81, Superlite Green Seal ve ek sac takviyesi**, özellikle kaplamalı menteşelerde etkili olmuştur. Ancak kaplamasız menteşelerde ara katman uygulamaları tek başına yeterli koruma sağlayamamıştır.

Sonuç olarak, kontak korozyonunun önlenmesinde en etkili yaklaşımın, **yüzey kaplaması ile birlikte ara katman izolasyonu kombinasyonu** olduğu belirlenmiştir. Özellikle çinko içeren çelik yüzeyler ile alüminyum arasında oluşabilecek potansiyel farklar nedeniyle galvanik korozyon riskinin yüksek olduğu ve bu riskin ancak bütüncül bir koruma stratejisi ile azaltılabileceği deneysel olarak kanıtlanmıştır.

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ANALYSIS OF COMPARATIVE CONCENTRATIONS OF MICROPLASTICS IN SOIL AND PLANT ORGANS

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ABSTRACT
Microplastics, tiny particles of synthetic polymers and plastics measuring less than 5 millimeters, enter the environment in various ways and are difficult to degrade, posing potential risks to the entire ecosystem. The growing concern about the impact of microplastics on terrestrial ecosystems and plants has led to increased attention on this issue. This study analyzes the concentration of microplastics in soil and plant parts of *Coccinia grandis* collected from selected sites. The study area, located in and around Thiruvananthapuram city, Kerala, includes sites such as the Akkulam Road dump site, Veli Lake Road, Kochullor, Pattom-Pottakuzhi Road, Manvila, Sreekaryam, Technopark-Karyavattom, Kazhakuttom railway station, Kesavadasapuram, and areas near the Central Tuber Crops Research Institute (CTCRI) in Thiruvananthapuram District, Kerala, India. A key aspect of this study was the separation of microplastics from the soil, with methods such as sampling, extraction, purification, and identification applied to complex environmental matrices. Larger plastic particles were manually sorted out during the process. Standard procedures were used to estimate essential soil parameters, and a comparative analysis of these results was also conducted. The collected plant materials were analyzed using FTIR spectroscopy to identify the presence of microplastics in plant organs. The results provided evidence of plants' microplastic uptake.

1. INTRODUCTION

Microplastics (MPs) are emerging as persistent contaminants with notable effects on biological and ecosystem functions. These polymer-based particles, typically less than 5 mm in size, have become iconic representations of anthropogenic waste and environmental pollution. MP pollution is now considered one of the greatest threats to the earth system. Their presence is nearly ubiquitous across both freshwater and marine ecosystems. However, the impact of plastics in terrestrial environments remains poorly understood.

Reports indicate that MPs can influence plant growth, alter the inherent properties of soil, and modify the composition and activity of microbial communities. A significant source of MP pollution has been traced to wastewater discharges and biosolids/SS, which are by-products of wastewater treatment plants (WWTPs) (Enfrin et al., 2019). MPs have been found in agricultural soils (Corradini et al., 2019a), especially in those receiving sludge compost (Corradini et al., 2019a). Other affected areas include soils in suburban built environments (Liu et al., 2018), coastal soils (Zhou et al., 2018), forest soils near farmlands (Zhang et al. 2022), and landfills with refuse and leachates (He et al., 2019). Additional sources include landfills, beach litter, and runoff from farming and industrial, urban, and recreational spaces (Hurley and Nizzetto, 2018). Several studies have demonstrated that the migration of MPs through the food chain alters biological communities. As the particle size of MPs decreases, their accumulation and transmission along the food chain increase, ultimately reaching humans (Farrell and Nelson, 2013).

OBJECTIVES OF THE STUDY

- To assess the soil parameters of the collected samples
- To characterize the microplastics present in soil samples from various sites
- To evaluate the concentration of microplastics in different plant organs
- To investigate the presence of microplastics in *Coccinia grandis* using FT-IR analysis
-

2. MATERIALS AND METHODS

2.1. STUDY AREA

In this study eleven waste dumping sites in Trivandrum district of Kerala were selected for the collection of soil samples. They are listed below.

SITE 1. Akkulam Kayalroad (Latitude 8° 31' 26.9004" N, Longitude 76° 56' 11.8968" E)
SITE 2: Veli lake (Latitude: 8° 30' 57.97" N, Longitude: 76° 53' 25.53" E)
SITE 3.Kochullour (Latitude: 8° 32' 1.79" N, Longitude: 76° 55' 27.59" E)
SITE 4.Pattom,Pottakuzhi road(Latitude 8° 31' 15.3444" N, Longitude 76° 56' 28.3200" E)
SITE 5. Manvila (Latitude: 8° 32' 26.99" N, Longitude: 76° 54' 13.49" E)
SITE 6.Sreekaryam main road(Latitude: 8° 32' 28.68" N, Longitude: 76° 54' 40.68" E)
SITE 7.Technopark (Latitude: 8° 33' 18.59"N, Longitude: 76° 52' 31.79" E)
SITE 8.Kazhakuttom railway station (Latitude 8 .556°N, Longitude 76.872°E)
SITE 9.Kesavadasapuram (Latitude 8°31'45.22"N, Longitude DMS: 76°56'23.35"E)
SITE 10. CTCRI, Sreekaryam (Latitude: 8° 23' 59.99" N, Longitude: 76° 58' 59.99" E)
SITE 11. CTCRI Sreekaryam (Latitude 8° 26' 26.39" N, Longitude: 76° 59' 19.79" E)

Plate 1. Study area

2.2. PLANT MATERIAL

Coccinia grandis, commonly known as baby watermelon, is a perennial herbaceous plant belonging to the Cucurbitaceae family. The plant is widely recognized for its edible fruit, which is commonly used as a vegetable in various regions across the globe. *Coccinia grandis* can propagate both vegetatively and through seeds, ensuring its widespread growth.

The plant's leaves are palmately arranged and simple, typically with five lobes. The tendrils are long, elastic, and measure around 5 cm in width and 4 cm in diameter. Additionally, the flowers

of Coccinia grandis are quite distinctive—large, white, and characterized by five long, tubular petals. Notably, Coccinia grandis is a perennial plant, meaning it lives for more than two years, contributing to its persistent growth and fruit production year after year.

Plate *2. Coccinia grandis*

2.3. METHODOLOGY

2.3.1. COLLECTION OF SOIL SAMPLES

The soil samples were gathered from the designated sites, stored in zip-lock bags, and set aside for subsequent analysis alongside the plant specimens. Additionally, large plastic debris was collected for visual identification, labeled, and transported to the laboratory for further processing.

Plate 3: Sample processing

The following soil parameters were estimated:

1. Estimation of soil organic carbon (Walkley, A.J. and Black, I.A., 1934)
2. Estimation of total alkanity (APHA, 1992)
3. Estimation of Chloride (Vogel, 1989)
4. Estimation of Acidity (Kotrly S and Sucha1985)
5. Estimation of pH of soil samples (Riddle and Peter, 2013)
6. Estimation of Phosphorus (Berenblum I and Chain E, 1938)
7. Estimation of Potassium (Whittles C. L. and Little, R. C. 1950).

The stereoscopic analysis of *Coccinia grandis* stem section and FTIR spectroscopy detection of microplastics in plant organs were also done.

2.3.2. Preliminary investigation and physical characterization of microplastics

The physical characterization of microplastics is essential for determining various attributes such as particle size, color, shape, morphology, corrosion, and aging degree (Hidalgo-Ruz et al., 2012). However, the identification and quantification of microplastics remain time-consuming and labor-intensive processes. Traditionally, visual characterization often with or without a microscope

has been the primary method for identification (Munno et al., 2018), though it offers low accuracy. To begin the analysis, microplastics collected from different samples are first examined to identify their color, size, and shape, as well as for preliminary quantification.

Plate 4. Digestion of Plant Material

3. RESULTS AND DISCUSSION

Environmental pollution caused by microplastics (MPs) has become a significant anthropogenic threat to the biosphere and is a growing global concern. MPs are responsible for numerous alterations in soil physicochemical properties, including changes in porosity, enzymatic and microbial activities, as well as plant growth and yield. Due to their widespread presence, high specific surface area, and strong hydrophobic properties, MPs exhibit considerable variability. According to studies by Warrier et al, 2022, MPs can differ in size (ranging from 0.1 µm to 5 mm) and shape (such as fragments, foams, lines, pellets, fibers, and films), be composed of various polymer types (including polyethylene, polystyrene, polyethylene terephthalate, polypropylene, and polyvinyl chloride), and have densities ranging from 0.89 to 1.58 g cm−3.

3.1 PRELIMINARY INVESTIGATION OF MICROPLASTICS IN SOIL SAMPLES

The preliminary identification of soil samples from various sites, as shown in Table 1, reveals that all the selected sites were contaminated with plastics. The highest concentration of particles was found at Site 11, where 45 particles were collected from the 300 µm sieve size and 33 particles from the 1 mm sieve size. This was followed by Site 7, which had particles measured as 31, 42, and 39 from the 300 µm, 1 mm, and 2 mm sieve sizes, respectively. The transportation pathways of microplastics (MPs) are complex, influenced by changes in physicochemical characteristics, biofouling processes, further fragmentation, aggregation, and interactions with biota. Plastic mulching and degradation are occurring across many sites, resulting in a high accumulation of plastic content mixed with soil matter. Common plastic fragments found in the

samples include polythene covers, thermocol, and cigarette packs. MPs are observed in a variety of colors.

The most commonly observed microplastic pattern in the samples consisted of irregular white and transparent fragments, similar to findings reported in the literature. According to previous studies, transparent particles were the most prevalent, making up 50% of the samples, while white particles accounted for 23%. Colorful plastics, including black, blue, green, red, and other colors, comprised the remaining 27%. Our results also revealed a significant proportion of microplastics with white characteristics. One possible source of these transparent and white particles could be plastic bags, which are widely used in everyday life. The appearance of colorless particles might also result from the fading of colors in some colored plastics, particularly lines and films, once they enter surface waters. Additionally, certain white plastics may have turned pale yellow, showing rounded corners due to environmental exposure (Marti, E et al., 2020).

Table.1 Preliminary investigation of microplastics

Sample No.	Shape Colour	Sieve size 4.75 mm	Sieve size 2 mm	Sieve size 1 mm	Sieve size 300 mic
1	Transparent irregular fragments	6	12	17	14
2	White angular fragments	3	12	21	15
3	White and transparent fiber like	3	16	28	25
4	White elongated fiber like	15	26	10	17
5	White, transparent irregular fragments	3	6	10	18
6	Transparent, white fiber like	2	8	18	12
7	White, gold, silver, distorted fragments	3	39	42	31
8	White, distorted angular fragments	3	12	8	14
9	Blue, transparent, white, distorted fragments	3	2	3	5
10	White elongated fiber like	3	16	39	11
11	White, transparent irregular fragments	5	18	33	45

3.2 Estimation of soil organic carbon

The soil organic carbon (SOC) concentrations of eleven soil samples are presented in Table 2. Among these, the highest SOC concentration is found in sample 3 (12.96%), followed by sample 8 (12.45%), sample 2 (11.78%), sample 6 (11.52%), sample 7 (11.44%), sample 11, and sample 1 (11.35%). Sample 10 has a concentration of 11.18%, while sample 9 contains 10.93%. Sample 5 shows a much lower concentration at 5.02%, and the lowest SOC concentration is observed in sample 4 (4.64%). Recent studies indicate that microplastics can influence carbon and nutrient cycling through dissolved organic matter (Li S et al., 2024). The microbial degradation of plastic

polymers is thought to play a significant role in soil carbon cycling (Rillig et al., 2021; Skariyachan et al., 2022). Small amounts (0.11–0.48%) of bio-labile dissolved organic carbon (DOC) released from microplastics stimulate microbial activity, thereby contributing to the turnover of soil organic carbon (Romera-Castillo et al., 2018). Therefore, it can be inferred that factors such as soil profile, temperature, moisture, and topography of the site area influence the SOC concentration.

Table 2. Soil organic matter

Sample No.	Weight of sample (gm)	SOC Content (%)
1	0.201	11.35
2	0.222	11.78
3	0.211	12.96
4	0.508	4.64
5	0.502	5.02
6	0.200	11.52
7	0.208	11.44
8	0.206	12.45
9	0.202	10.93
10	0.218	11.18
11	0.208	11.35

3.3 Estimation of Total alkalinity

Total Alkalinity (TA) refers to the quantity of dissolved alkali in water that can both release and absorb hydrogen ions. The total alkalinity levels of the eleven soil samples are presented in Table 3. Samples 4 and 5 exhibit the highest values of 300 mg/L, followed by samples 3, 6, 7, and 8, each showing 200 mg/L. Samples 2, 10, and 1, 9, and 11 displayed a total alkalinity of 150 mg/L and 100 mg/L, respectively. According to Allahbaksha, S., et al. (2018), the total alkalinity in their study ranged from 350 to 2250 mg/L, all exceeding the permissible limit of 200 mg/L. These findings align with the results observed at the Nanded landfill site. Water interacts with soils and rocks rich in carbonate minerals, and factors such as rainfall, acidic sanitizers, the addition of fill water, and other product applications can influence the total alkalinity in soil.

Table 3. Total Alkalinity

Sample No.	Volume of sample (ml)	Total alkalinity (mg/L)
1	10	100
2	10	150
3	10	200
4	10	300
5	10	300
6	10	200
7	10	200
8	10	200
9	10	100
10	10	150
11	10	100

3.4 Estimation of Chloride

Chloride is a vital plant nutrient that plays a role in photosynthesis and overall crop productivity. The chloride content in the soil samples, as presented in Table 4, showed that the highest concentration was found in sample 8 (2 M), followed by sample 11 (1.5 M), sample 5 (1.1 M), and sample 1 (1 M). Samples 3, 6, and 7 contain chloride levels of 0.6 M, while samples 2 and 4 have 0.4 M. The lowest chloride content is found in sample 9 (0.3 M). Based on this data, it can be inferred that the variations in chloride levels across the soil samples may be influenced by local ecosystem changes and soil fertility, potentially due to the use of plastic mulching.

Table 4. Chloride content

Sample No.	Volume of sample (ml)	Chloride content (M)
1	10	1
2	10	0.4
3	10	0.6
4	10	0.4
5	10	1.1
6	10	0.6
7	10	0.6
8	10	2
9	10	0.1
10	10	0.3
11	10	1.5

3.5 Estimation of Acidity

The acidity content of selected samples is shown in Table 5. From this study, it was found that the highest acidity value of 100 mg/L was observed in samples No. 3, 4, 7, and 9, followed by 50 mg/L in the remaining samples. According to the study, MPs altered the pH in different soil types, with PE microplastics lowering pH in acidic soils and increasing pH in alkaline soils (Dissanayake et al., 2022). The accumulation of plastic and changes in the soil profile affected the acidic variations. Therefore, it could be suggested that the presence of microplastics in soil samples influenced the acidity content of the selected soil samples.

Table 5. Acidity

Sample No.	Volume of sample (ml)	Acidity content (mg/L)
1	10	50
2	10	50
3	10	100
4	10	100
5	10	50
6	10	50
7	10	100
8	10	50
9	10	100
10	10	50
11	10	50

3.6 Estimation of pH

The pH values of the sample soils are presented in Table 6. The highest pH, 6.4, was observed in sample 3, while the remaining samples showed pH values ranging from 5.5 to 6.3. Sample 2 had a pH of 6.3, and samples 4, 5, and 9 exhibited pH values of 6.2. A pH of 6.1 was recorded for samples 1, 6, 10, and 11, while sample 7 showed a pH of 6. The lowest pH value, 5.7, was observed in sample 8. Based on these results, it could be assumed that the soil samples were predominantly of an acidic type.

It was found that soil pH increased with the presence of foams and fragments, with a slight increase observed in the case of films. Microplastics were shown to increase soil pH and reduce microbial activity, depending on their shape, polymer type, and exposure time. Previous studies indicated that microplastics alter soil pH through interactions with various organic and inorganic components, including cations and protons(Kokalj, A., 2022). Qi et al. (2020) also studied the effect of LDPE and biodegradable mulch on soil chemistry, finding that microplastics raise soil pH. Therefore, it can be assumed that the higher pH values observed in the soil samples were likely due to the interaction between the soil and microplastic compounds.

Table 6. Soil pH

Sample No.	Volume of sample (ml)	pH
1	10	6.1
2	10	6.3
3	10	6.4
4	10	6.2
5	10	6.2
6	10	6.1
7	10	6.0
8	10	5.7
9	10	6.2
10	10	6.1
11	10	6.1

3.7 Estimation of Phosphorus

Phosphorus is an essential mineral in soil. The available Phosphorus content in the sample sites was shown in Table 7. The highest Phosphorus availability was found in sample 5 (234.9 kg/ha), followed by sample 7 (211.7 kg/ha), sample 2 (175 kg/ha), sample 10 (153.81 kg/ha), sample 4 (143 kg/ha), sample 6 (134.9 kg/ha), sample 11 (134.7 kg/ha), sample 1 (113 kg/ha), sample 8 (78.29 kg/ha), and sample 9 (69.87 kg/ha). The lowest Phosphorus availability was observed in sample 3 (67.89 kg/ha). Recent research also suggested that microplastics alter carbon and nutrient cycling through dissolved organic matter (DOM). The input of PP MPs into soil significantly increased soil DOC, N, and P levels (Liu et al., 2017). Therefore, it could be assumed that the rise in Phosphorus availability at the sample sites was in response to microplastic landfilling.

Table 7. Estimation of Phosphorus

Sl.no	Available Phosphorus (kg/ha)	Rating
1	113	High
2	175	High
3	67.89	High
4	143	High
5	234.9	High
6	134.9	High
7	211.7	High
8	78.29	High
9	69.87	High
10	153.81	High
11	134.7	High

3.8 Estimation of Potassium

Potassium was essential in nearly all processes needed to sustain plant growth and reproduction. The Available Potassium content in soil samples, shown in Table 8, indicated that all samples exhibited high potassium availability. Among them, sample 3 had the highest value of 1512.1 kg/ha, followed by sample 1 (992.5 kg/ha), sample 2 (878.7 kg/ha), sample 10 (814.1 kg/ha), sample 11 (789.9 kg/ha), sample 9 (765.8 kg/ha), sample 7 (647.3 kg/ha), sample 8 (633.4 kg/ha), and sample 6 (546.7 kg/ha). The lowest potassium availability was observed in sample 4, with 545.7 kg/ha. A recent research paper(Yan et al., 2023) reported that microplastics altered the leaching of nitrogen and potassium in Mollisols. It was also found that high application rates or smaller sizes of microplastics showed negative effects on available phosphorus (AP) and available potassium (AK) concentrations but stimulated soil pH compared to the control. Thus, it was understood that the increase in potassium availability was influenced by microplastic mulching at the sample sites.

Table 8. Estimation of Potassium

Sl.no	Available Potassium (kg/ha)	Rating
1	992.5	High
2	878.7	High
3	1512.1	High
4	545.7	High
5	587.9	High
6	546 7	High
7	647.3	High
8	633.4	High
9	765.8	High
10	814.1	High
11	789.9	High

3.9. Stereoscopic detection of *Coccinia grandis* stem section

The stereoscopic analysis of *Coccinia grandis* stem sections was shown in Plate 4. From this analysis, it could be assumed that the stem wall exhibited some stress conditions compared to a normal *Coccinia grandis* stem section (N). Although the exact mechanism causing the stronger inhibitory effect of plastics remained unclear, normal Coccinia stems had a wavy hair outline. Uniserate, multicellular hairs were present, while in the Coccinia sample, stem hairs were least present. The outer surface was cutinized. The pith cells were broken, and the hollow center was marked by disorganized irregular cavities, inhibiting plant growth due to the increased difficulty in obtaining nutrients. The sizes and shapes of the residues produced by PLA plastics may also have been important factors influencing plant growth. Microplastics could affect the biomass of plant communities through a variety of mechanisms, such as direct toxicity, changes in soil structure, nutrient immobilization, and effects on the soil microbial community and root symbionts (Khalid et al., 2020; Rillig et al., 2019), including the site of lateral root emergence to the stele through the crack-entry mode.

According to the studies of Ma et al. (2010), microplastics accumulation in plants triggered a blockage effect on cell wall pores, which was similarly observed in our sample section C. Stem hair growth was suppressed in the sample sections compared to the normal section. One study on the accumulation and distribution of nanoplastics revealed that they could move across cells via the liquid phase of endocytosis and vascular systems within the plant body (Chae & An, 2020; Lian et al., 2020a, b), showing similar observations in sample C. Changes in the elementary tissue composition of the stem section were assumed to have occurred in the sample grown in the presence of various microplastics, as the present study undertook a similar analysis. The presence of microplastics at the sample site directly or indirectly influenced the growth of *Coccinia grandis* and its morphological parameters.

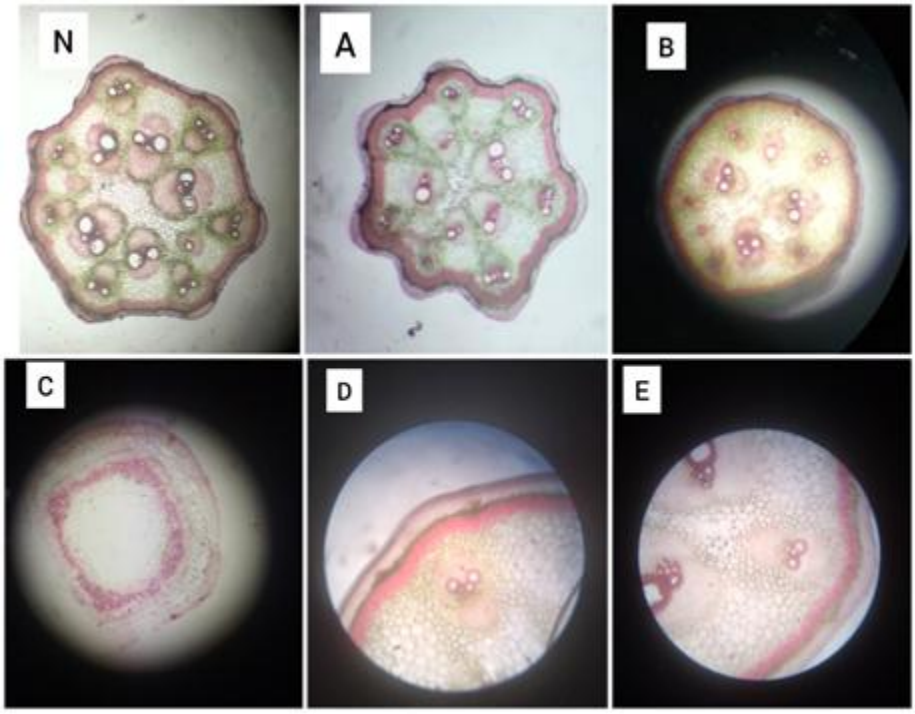

Plate 4. Stereoscopic detection of Coccinia grandis stem

3.10 FTIR spectroscopy detection

The FTIR spectrum of *Coccinia grandis* from various random sites is presented in Figure 1. Fourier-transform infrared (FTIR) spectroscopy was utilized to identify the chemical structure of the sample. The vibrational frequencies corresponding to the functional groups of the pure drug remained consistent in the physical mixture containing *Coccinia grandis*, indicating that no significant interaction occurred in this study. The O-H group and the carbonyl (C=O) stretching peak observed at 1629.85 cm−1 in the FTIR spectrum confirmed the chemical nature of *Coccinia grandis* mucilage. Additionally, the presence of a polymer-type PVP peak in selected samples further validated the chemical composition.

Polyvinylpyrrolidone (PVP), also known as polyvidone or povidone, is a biodegradable, water-soluble polymer derived from the monomer N-vinylpyrrolidone. PVP is an inert, non-toxic, temperature-resistant, pH-stable, biocompatible, and biodegradable polymer that helps encapsulate and cater to both hydrophilic and lipophilic drugs. PVP is a versatile ingredient used in the cosmetics and beauty industry as a binder, film former, emulsion stabilizer, suspending agent, and hair fixative. It is primarily found in products such as mascara, eyeliner, hair conditioners, hair sprays, shampoos, and other hair care products. Thus, based on these observations, it was concluded that within the short duration of the study, there was minimal uptake of microplastics into the selected plant in the study area. It could be assumed that microplastics had some influence on the natural polymer incorporation into the plant **(**Rillig, M. C., et al. 2019**).**

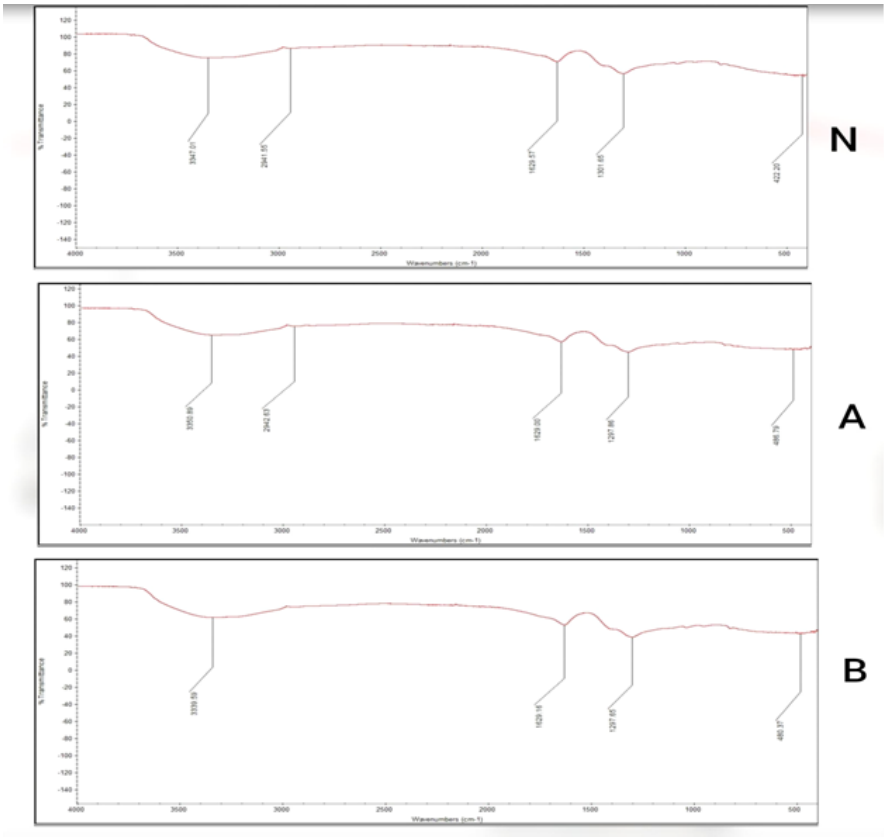

Fig 1. FTIR Spectrum of *Coccinia grandis* control plant(N) and FTIR spectrum and C*occinia grandi*s from Sample sites A and B

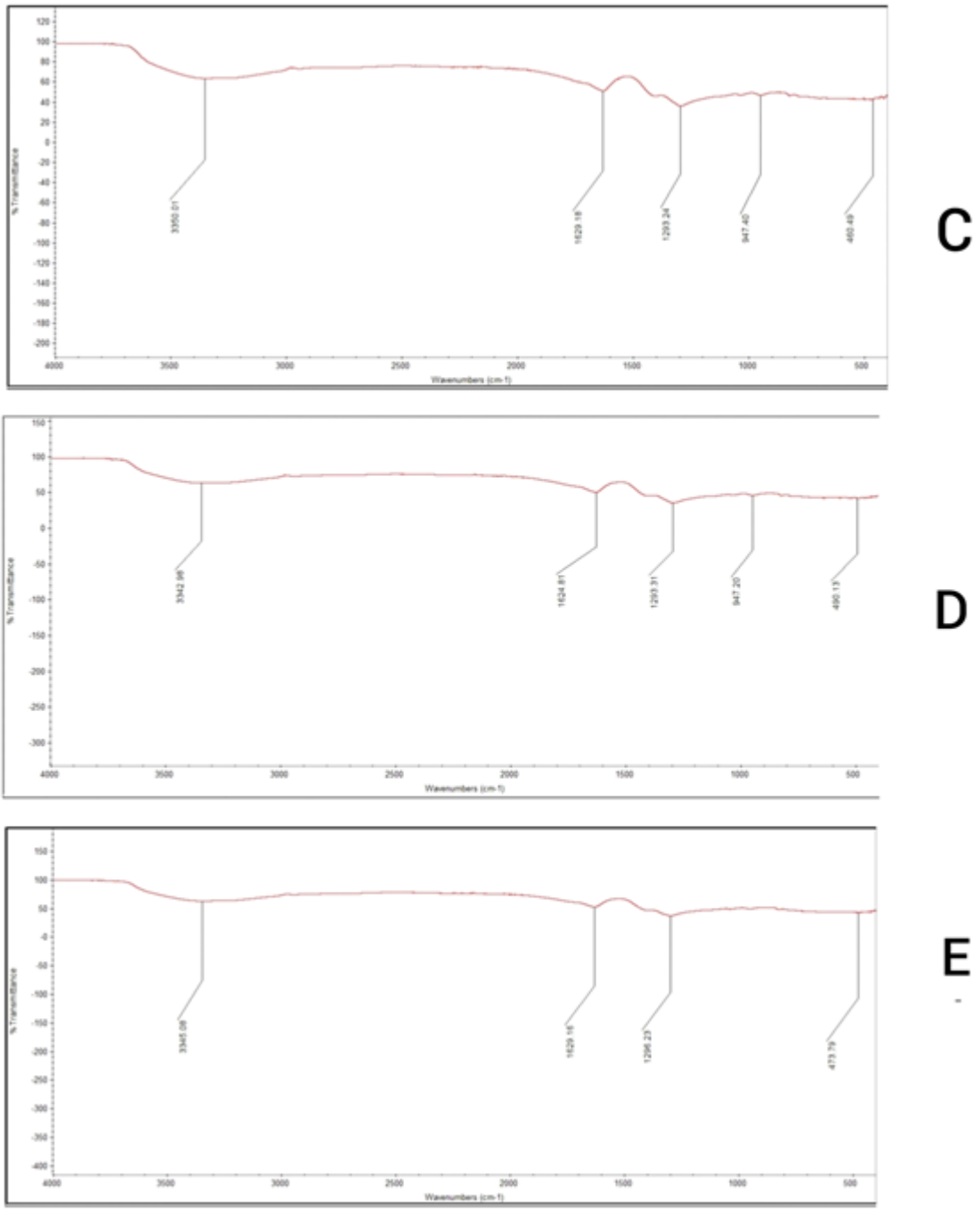

Fig.2. FTIR spectrum of Coccinia grandis stem sections of sample sites C, D and E

4. SUMMARY AND CONCLUSION

Plastic pollution is widespread, and its effects are long-lasting. As a synthetic chemical, plastic is considered an emerging pollutant due to its detrimental impacts on the terrestrial environment. In the Trivandrum district, selected sampling sites highlight the significant presence of microplastic pollution and the various types of microplastics found. While data on the abundance and concentration of microplastics in soil and plant organs are available, the results fluctuate due

to rapidly changing environmental factors and human activities. Nevertheless, this study provides valuable descriptive data, shedding light on the influence of microplastics on soil and plant organs. The majority of research has focused on soil characteristics, with sample analyses examining aspects such as physicochemical properties, chemical composition, and the occurrence of microplastics. In addition, plant samples have been studied to assess biochemical and physiological effects. The establishment of standardized methods for isolating, detecting, and tracking microplastics in soil and plant tissues would significantly advance future research. Soil samples collected near water bodies, hospitals, and irrigation areas exhibit higher concentrations of microplastics, with soil parameters showing considerable variation, likely due to the composition and type of plastic polymers being disposed of in these areas.

Soils are likely sinks for microplastics, and their behavior across different sampling sites varies depending on the polymer type and composition of the microplastics. This, in turn, influences various soil chemical parameters such as pH, alkalinity, acidity, soil organic carbon, potassium, and phosphorus levels, all of which change based on the specific sampling site. Globally, typical microplastic concentrations can reach up to 13,000 items per kg of dry soil and 4.5 mg per kg of dry soil, with some individual plots showing concentrations exceeding these figures. Within the selected sample sites, microplastics are present at significant concentrations.
The rise in soil organic carbon (SOC) in the studied soils suggests that variations in moisture content and nutrient availability may be driving the increase in SOC levels, possibly due to the high concentration of microplastics. The observed variation in SOC content indicates that changes in moisture during soil treatment are influenced by the SOC, which subsequently affects the chemical and physical properties of the soil.

The high levels of potassium and phosphorus in the soil samples suggest that microplastics might enhance nutrient uptake in these soils. Additionally, microplastic-mulched sites tend to promote plant growth. It can thus be concluded that microplastic contamination does not significantly hinder soil nutrient absorption or plant growth. However, prolonged microplastic presence could disrupt the optimal nutrient concentrations in the soil, potentially leading to toxicological effects over time.

This study illustrated that the concentration of microplastics and the different particle sizes exerted varying effects on soil properties and physiological responses, including soil pH, available CL, and concentrations of P and K, which influenced soil nutrient availability and affected soil-dependent factors. The presence of microplastics at sample sites altered the nutrient content to a significant extent and also influenced plant growth in the dumping area.

The bioaccumulation of microplastics in plant tissues required further exposure and timely uptake for better analysis. The root exudates and mucilage were factors that hindered the uptake. The PVP (polyvinylpyrrolidone) natural polymer vibration stretching peak observed in FTIR diagnosis suggested that the microplastic polymer, resembling the PVP structure, might have undergone uptake in plant organs.

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PRICE ELASTICITY ANALYSIS IN A DOUBLE MACHINE LEARNING FRAMEWORK: AN IMPROVED METHODOLOGICAL MODEL

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ABSTRACT
In the era of digital transformation, economic data structures are becoming increasingly complex and voluminous, rendering traditional econometric modeling approaches insufficient to cope with these evolving dynamics. Fundamental challenges such as endogeneity, model misspecification, and high dimensionality have raised concerns about the validity and reliability of conventional methods. In this context, the importance of data-driven methods that are more flexible, free from bias and able to deal with high-dimensional data structures has increased. This paper compares classical econometric methods and contemporary causal machine learning approaches for estimating the price elasticity of demand at the theoretical level; in particular, the third generation Dual Machine Learning model (DML3) is examined in depth from a methodological perspective. As a further extension of the DML framework developed by Chernozhukov et al. (2018), the DML3 model combines ensemble learning, nested cross-fitting, robust score functions and iterative improvement mechanisms to provide a powerful causal forecasting framework. The DML3 model overcomes the limitations of earlier DML approaches by integrating robust scoring metrics, including Huber loss and Tukey's biweight function. It is further empowered by contemporary algorithms such as Random Forest, LASSO, XGBoost, LightGBM, Deep Neural Networks, and Gradient Boosting Regressors. In conclusion, the DML3 model is a valuable contribution to the literature as a new approach to perform causal inference in high-dimensional data environments in a more reliable, flexible and methodologically sound way.
Keywords: Price elasticity, Double Machine Learning, causal inference, machine learning, econometric modeling, high-dimensional data

1. INTRODUCTION

The ongoing wave of digital transformation has profoundly expanded the volume, diversity, and complexity of data structures employed in economic decision-making processes. This evolutionary development has made more visible the limitations of traditional econometric models in accurately estimating causal relationships, especially in the case of high-dimensional and non-linear data patterns. In this context, there is a growing need for more flexible, robust and data-driven methods in key areas of economic analysis, such as understanding consumer behavior and measuring the effectiveness of public policies.

Classical methods such as Ordinary Least Squares (OLS), Instrumental Variables (IV), Panel Data Models and Difference-in-Differences (DiD) are still widely used in applied econometric research, but they remain vulnerable to structural problems such as endogeneity, multicollinearity and model misspecification. Especially in data environments with a large number of control variables or nonlinear relationship structures, the forecasting performance of these models is severely weakened. This underscores the growing necessity for a new generation of modeling frameworks that integrate theoretical soundness with empirical adaptability in data-rich economic contexts. The Double Machine Learning (DML) approach, developed in line with this need, stands out as an innovative method that combines cross-fitting and orthogonalization techniques to make causal inference more reliable in high-dimensional data sets. This approach, developed by Chernozhukov et al. (2018), allows the causal relationship representing the treatment effect to be estimated with lower bias by separating it from the disturbance functions related to control variables.

This research introduces the DML3 model, which is proposed as a third-generation evolution of the DML method and demonstrates its methodological advantages over classical econometric methods and previous DML versions. Combining ensemble learning, nested cross-fitting, robust score functions and iterative refinement mechanisms in a holistic structure, the DML3 model offers a new methodological paradigm in terms of both generalization ability and forecast stability in high-dimensional data environments. In this context, the main objective of this study is to propose a theoretical framework that can predict a strategically important economic indicator such as price elasticity in a more robust and flexible way beyond the classical approaches.

1.1. Literature Review

In recent years, the structural and methodological limitations of classical econometric methods in price elasticity analysis have led researchers to develop more flexible and highly accurate models. In this direction, the Double Machine Learning (DML) method, which stands out with its potential to increase the causal inference power in high-dimensional data environments, has taken its place as a strong alternative in the literature. Chernozhukov et al. (2018) laid the theoretical foundation of the DML method and developed a structure that enables unbiased causal effect estimation under high-dimensional control variables. Heijenga (2018), in his study on historical slave trade data in Africa, found that DML improves estimation accuracy and narrows confidence intervals. Chang (2020) developed the “DMLDiD” method by integrating the classical Difference-in-Differences (DiD) approach with DML and showed that this structure provides more reliable causal inference in high-dimensional data. Kaunismäki (2021), using data from a retail firm in Finland, showed that DML provides more accurate and reliable forecasts compared to classical methods such as OLS and IV, with the AdaBoost algorithm being particularly prominent. Kumar et al. (2022) emphasized that DML provides more objective and robust results in macroeconomic policy analysis, while Mucollari & Minotti (2022) showed that DML provides

stronger price elasticity estimates than DiD in e-commerce data and that deep learning-based preprocessing techniques improve model performance. Kristiansson (2023) emphasized the dynamic nature of algorithmic models by developing customer segment-specific pricing strategies with DML in the insurance industry. In the same year, Ezzeldin (2023) demonstrated that DML, together with Random Forest and LASSO algorithms, provides flexible and unbiased forecasts on avocado sales data. While Movaghari (2024) states that DML and Causal Forest methods produce more robust outputs than classical models in firm-level financial decision-making processes, Rafizadeh (2024), in his analysis on US gasoline demand, states that DML provides more accurate results with narrower confidence intervals compared to 2OLS. Finally, Hobballah (2024), focusing on e-commerce and retail sectors, emphasizes that the integration of DML with advanced machine learning algorithms provides more effective results in big data environments. This chronological literature summary demonstrates that DML provides more flexible, low-bias and methodologically sound results than classical econometric approaches in different sectors and data structures, supporting the potential of the method to become a new standard in economic analysis.

2. RESEARCH AND FINDINGS

2.1. Method

This research compares and contrasts traditional econometric approaches with modern methods based on machine learning to estimate demand elasticity. Traditional methods include Ordinary Least Squares (OLS), Instrumental Variables (IV) and Panel Data Models, while modern methods include DML1, DML2 and the proposed DML3 models developed within the framework of Dual Machine Learning (DML). The implementation process started with the data preprocessing steps and ended with the modeling and performance analysis stages. The overall methodology of the research is presented schematically in Figure 1.

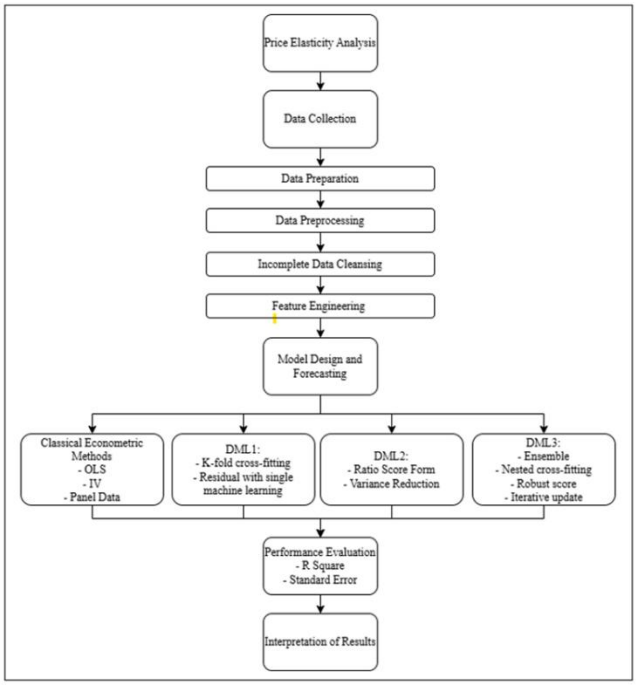

Figure 2.1. Research Methodology

DML approaches provide a strong methodological basis for estimating causal effects more reliably, especially in high-dimensional data environments. In the DML method, the relationship between the independent variable (price) and the dependent variable (demand) is measured in terms of the parameter θ, net of disturbance functions. In the model, both price and demand variables are logarithmically transformed. This makes it possible to directly interpret the percentage effect of price changes on demand. The log-log model is partially linear in accordance with the DML framework and the effect of control variables is represented by a separate function.

The DML method consists of two main stages. In the first stage, the relationships between the dependent variable and the control variables and between the independent variable and the control variables are modeled by machine learning algorithms and nuisance functions are constructed using the predictions obtained from these predictions. In the second stage, residuals from these estimates are used to quantify the pure causal effect. The process is supported by cross-fitting, Neyman orthogonalization and robust score functions. In addition, robust loss functions such as Huber loss are used instead of classical moment conditions to reduce the effect of outliers. In the modeling process, price and demand variables are log-transformed so that the percentage effect of price changes on demand can be calculated directly. The log-log model is adapted to the DML framework and transformed into a partial linear model, where the effect of control variables is represented by a separate function. Thus, the price elasticity coefficient is estimated explicitly by removing the effect of other variables.

DML models are analyzed in three basic structures:

- DML1: The dataset is divided into K layers (folds) and the nuisance functions in each layer are estimated by machine learning. Then, a classical regression is applied on the residual values to estimate θ for each layer and the final result is obtained by averaging these values. However, since this structure does not include variance reduction, high volatility and drift problems were observed in some cases.
- DML2: In order to provide more robust estimates compared to DML1, we use ratio-based score functions with variance reduction. Again, the K-fold cross-fit structure is retained, but this time a single estimate of θ is obtained. Model flexibility is limited due to the use of only one machine learning algorithm.
- DML3: The DML3 model developed in this study is a more advanced structure that aims to overcome the limitations of previous approaches. In this model, nested cross-fitting is applied to estimate both nuisance functions and θ in a more robust validation process. In the prediction process, multiple machine learning algorithms such as LASSO, Random Forest, GBM and LightGBM were used together and an ensemble learning approach was adopted. In the second-stage predictions based on residual values, robust score functions such as Huber loss are used instead of classical moment conditions. Moreover, iterative update steps are applied to improve the accuracy and stability of the model predictions.

The application was performed with the NYC Yellow Taxi dataset and the DML3 model stood out with low bias, high R^2 and superior performance against outliers.

A comparative table summarizing the main differences of the three DML models is presented below:

Table 2.1. Comparative Characteristics of DML Methods

Feature	DML1	DML2	DML3
Cross-Fitting	Single-layer	Single-layer	Two-layer (Nested)
ML Utilization	Single algorithm	Single algorithm	Ensemble (Multiple algorithms)
Variance Reduction	None	Ratio Score Function	Ensemble + Robust Score Functions
Outlier Robustness	None	Partial	High
Iterative Update	No	No	Yes

As a result of the model comparisons, it was observed that DML1 offers a fast and simple structure but suffers from high variance. DML2 produced more stable results thanks to variance reduction, but was limited in terms of flexibility due to its reliance on a single algorithm. DML3 showed the best performance in terms of both prediction accuracy and model stability. Especially in high-dimensional and outlier data sets, DML3 stood out with lower bias and higher R^2 values. The modeling and evaluation processes were carried out using the New York City Yellow Taxi dataset. Price (P) and demand (Q) variables were modeled logarithmically, and factors such as travel time, distance, number of passengers and time of day were included as control variables. In the implementation process, all three DML models were applied separately and the results were compared. The findings reveal that the DML3 model produces more successful and reliable results in price elasticity estimation.

2.2. Findings

A comparison of the statistical performance of the applied models reveals that classical econometric approaches have serious limitations in high-dimensional data environments. These methods lose stability in the face of complexity in the data structure and a large number of control variables. The DML3 model outperformed DML1 and DML2 with lower bias, smaller variance and higher explanatory power (R^2). The model's high robustness to outliers, combined with its ability to produce consistent results, increased analytical confidence. This was made possible in particular by combining the building blocks of ensemble learning, robust score functions and nested cross-validation. The results prove that DML3 provides a more accurate and reliable picture of the price-demand relationship.

2.2. Discussion

The findings point not only to a technical advance but also to a fundamental transformation in the methodological perspective. Traditional econometric methods are inadequate for today's complex and multidimensional data patterns, necessitating more flexible, robust and predictive approaches.

The DML3 model fills this gap and stands out as a powerful tool in terms of both forecast accuracy and application flexibility. In particular, its high robustness to outliers and model stability make it a viable solution in various sectors.

In economic applications, the price elasticity coefficients obtained with DML3 allow policymakers to develop more responsive, targeted and effective strategies. This shows that the model is not only an analysis tool but also a strategic building block that can be integrated into decision support systems.

3. CONCLUSION

This paper aims to provide a stronger, more flexible and methodologically sound approach to price elasticity estimation in high-dimensional data environments and introduces DML3, a third generation Dual Machine Learning model.

DML3 offers a new methodological framework by breaking the boundaries of classical methods and incorporating advanced components such as ensemble learning, nested cross-fitting and robust score functions under a single roof. The success of the model is notable not only technically but also in terms of reconstructing analytical strategies in applied economics.

In the future, it is proposed to apply DML3 in different sectors, data types and contextual structures, and even to integrate it with deep learning, real-time analytics and reinforcement learning to create hybrid frameworks. It is also proposed to develop hybrid models by integrating DML3 with emerging technologies such as deep learning, reinforcement learning or real-time analytics. Such an approach can increase the predictive power and operational efficiency of the model and contribute to its more efficient use in dynamic and uncertain environments. By combining the flexibility and stability required by modern data analytics, this approach can pave the way for innovative analysis in the field of economics.

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THE EFFECT OF CRYOGENIC COOLING AND COLD DEFORMATION ON MICROSTRUCTURAL FEATURES OF SOLUTION ANNEALED $CuNi_3SiCr$ ALLOY

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ABSTRACT
In this study, the effects of both the quenching medium (water and dry ice) and cold deformation (30%) on the structural properties of commercially extruded $CuNi_3SiCr$ alloy following solution annealing (900°C, 1 h) are investigated. The phase structure is monitored by microscopic examination for the alloy with variable conditions, and the crystallite size, microstrain and dislocation density of the materials are calculated depending on the condition. Metallurgical characterization studies indicate the presence of metal silicides (Ni_2Si and Cr_3Si) in homogeneous distribution within the α-copper matrix of the extruded alloy and the grains elongate due to cold deformation. Although the cooling with dry ice shows no significant change in the crystallite size of the alloy compared to the cooling in water, an increase in microstrain and dislocation density is detected. Electrical conductivity and hardness measurements reveal a significant change in the hardness of the alloy due to cryogenic and deformation effects. Also, EBSD recrystallization and GOS map studies show the energy stored in the alloy increases due to increased cooling efficiency and deformation. All these findings reveal how cryogenic cooling, and cold deformation affects (i) physical and mechanical properties, (ii) the precipitation kinetics during aging and (iii) the recrystallization tendency of the $CuNi_3SiCr$ alloy.
Keywords: $CuNi_3SiCr$ alloy, heat treatment, precipitation, recrystallization.

1. Introduction

Copper and copper alloys are widely preferred in the production of many electrical/electronic components due to their superior electrical and thermal conductivity. The sufficient mechanical properties, corrosion resistance, malleability of copper and its alloys enable them to be used preferably also in other industrial platforms (Chapman, 2016; Dabkowski & Yusheng, 2024; Kundig & Weed, 2006; Simon *et al.*, 1992). Although Cu-Be and CuCoNiBe alloys with high strength and conductivity have a significant usage area among copper alloys, there is also a significant restriction on the use of copper alloys containing beryllium due to the toxicity of beryllium metallurgy and today's environmental and health regulations (Chapman, 2016; Kızılbay, 2015). Therefore, thermo-mechanical processes specific to precipitation hardenable copper alloy compositions and high strength and high electrical conductivity matrix designs have been studied from past to present (Dong *et al.*, 2015; Gao *et al.*, 2002; Kim *et al.*, 2011; Koç & Kalkanlı, 2015; Li *et al.*, 2019; Matsuura *et al.*, 2022; Rdzawski & Stobrawa, 1993; Qin *et al.*, 2023; Xiao *et al.*, 2013). Precipitation hardenable CuNiSi alloys, also known as Corson alloys, have been developed as an alternative material to beryllium-containing copper alloys (Chapman, 2016; Corson, 1927). Alloying has an important place in the strengthening of Corson alloys, although it has a detrimental effect in terms of conductivity (Atapek *et al.*, 2024). Although the Ni:Si ratio in the composition of Corson alloys determines the strength level (Akkaş *et al.*, 2023; Hagino *et al.*, 2010; Lockyer & Noble, 1994; Sciezor *et al.*, 2023), it has been reported that alloying elements such as Al (Atapek *et al.*, 2024; Gholami *et al.*, 2017; Lei *et al.*, 2013), Mg (Altenberger *et al.*, 2015; Kuhn *et al.*, 2012; Monzen & Watanabe, 2008; Xiao *et al.*, 2020), Cr (Kuhn *et al.*, 2012; Popa *et al.*, 1996; Wang *et al.*, 2023), Zr (Popa *et al.*, 1996), Co (Horie *et al.*, 2020; Kuhn *et al.*, 2012) can also provide significant effects. It has been reported that these elements cause an increase in the fraction of nickel silicides, which are an important precipitate in the copper matrix, and the formation of metal silicides that can occupy these precipitates as property enhancers (Tao *et al.*, 2022). It is also known that elements such as Al and Mg have a grain refinement effect on solidification in Corson alloys (Gholami *et al.*, 2017; Monzen & Watanabe, 2008; Xiao *et al.*, 2020). It is also possible that elements such as chromium and cobalt can be found in nickel silicide crystals, while at the same time forming their own metal silicides (Kuhn *et al.*, 2007; Kuhn *et al.*, 2012; Wu *et al.*, 2019).

The significant effect of conventional heat treatment cycles, including solution annealing, quenching and aging stages, on the improvement of physical, chemical and mechanical properties of Corson alloys cannot be denied (Akkaş *et al.*, 2023; Lee *et al.*, 2014; Lei *et al.*, 2017; Li *et al.*, 2019; Tao *et al.*, 2022; Wu *et al.*, 2019; Xiao *et al.*, 2020). Several findings indicate that aging temperature and time can directly determine the hardness and electrical conductivity in CuNiSi alloy systems (Lee *et al.*, 2014; Lei *et al.*, 2017; Li *et al.*, 2019; Wang *et al.*, 2011; Wu *et al.*, 2019; Xiao *et al.*, 2020). It is possible to reduce distortion in the supersaturated copper matrix, to provide diffusion-controlled atomic mobility and submicron-sized precipitation, and to provide strength-conductivity optimization due to a significant increase in dislocation density through precipitate-dislocation interaction during aging (Lei *et al.*, 2017; Li *et al.*, 2019; Monzen & Watanabe, 2008; Wang *et al.*, 2023; Xiao *et al.*, 2020). In this whole process, the degree to which the alloy is in a supersaturated form at the quenching condition can also be a determining factor. It is a fact that subcooling following the solution annealing enables the formation of a supersaturated copper matrix (Sierpinski & Gryziecki, 1999). On the other hand, the positive effect of cold deformation of metals before aging following quenching is also known to increase ultimate strength (Sierpinski

& Gryziecki, 1999; Wang *et al.*, 2011). By deformation, regions with high dislocation density in the supersaturated matrix allow precipitates to nucleate, thus increasing the probability of precipitates forming in large numbers (Liu *et al.*, 2024). Nowadays, providing the quenching condition by cryogenic cooling after solution annealing and applying cold deformation immediately after aging is applied as an effective method for the optimization of the strength-conductivity of copper-based materials (Liao *et al.*, 2023a; Liao *et al.*, 2023b; Wang *et al.*, 2023). In this study, variable cooling conditions are achieved by performing both water quenching and dry ice cooling after conventional solution annealing on an extruded $CuNi_3SiCr$ alloy. Copper alloys cooled under variable conditions are also subjected to cold deformation and the structural features specific to the process are characterized. The findings reveal how cryogenic cooling, and cold deformation can be decisive on the precipitation and recrystallization kinetics of the alloy.

2. Experimental Procedure

In this study, thermo-mechanical processes are carried out on an extruded commercial Corson alloy ($CuNi_3SiCr$) and the alloy composition contains 1.8-3.0 Ni, 0.4-0.8 Si and 0.2-0.6 Cr (wt.%). The solution annealing process for the alloy includes a conventional heat treatment process, and the alloy is annealed at 900 °C for 1 h. The annealed alloys are cooled rapidly in two different environments. In the first cooling, the quenching process is carried out in the water environment (WQ) at room temperature. In the second cooling, the annealed alloy is cooled by immersing it in dry ice (IQ, -70 °C). The cooled alloys are then subjected to a 30% cold deformation in a single stage on a laboratory rolling mill.

The metallurgical features and structural properties of extruded and thermo-mechanically treated materials are determined by multiple analyses. Metallurgical characterization of the alloys is carried out by imaging the metallographically prepared samples with light microscope (LM, Olympus BX41M-LED) and scanning electron microscope (SEM, Jeol JSM 6060). Chemical composition of the precipitates is analyzed by using energy dispersive spectrometer (EDS, IXRF). Analyses performed with X-ray diffractometer (XRD, Rigaku Ultimate$^+$) are useful both in determining the phase within the alloys and in determining the crystal size (D), microstrain (ε) and dislocation density (ρ). In XRD analysis, the target material is Cu-Kα and scanning period is 30-80˚ (2θ) with the speed of 1°/min. All calculations on D, ε and ρ are made with equation solutions in accordance with referencing (Liao *et al.*, 2022; Liao *et al.*, 2023a; Wang *et al.*, 2014). Electron backscatter diffraction (EBSD, OXFORD AZtecHKL) and grain orientation spread (GOS) maps are determined in order to follow recrystallization characteristics of the studied alloys having different manufacturing conditions.

In order to determine the effects of cooling and deformation on the properties, changes in the hardness values and electrical conductivity levels of the matrices are monitored. A micro hardness tester (Zeiss MHT-10) is used for hardness measurements and multiple measurements are done under a load of 25 gf. The arithmetic value calculated after multiple measurements is evaluated as the average final hardness value. Electrical conductivity values of alloys with different conditions are also determined using a meter (Zappitec Series 1200) based on the Eddy current technique. Before electrical measurements, sample surfaces are polished to a mirror-like appearance and arithmetic mean values are determined after multiple measurements.

3. Results and Discussion

Figure 1 shows the SEM image of the etched matrix of the extruded alloy and the EDS mapping indicating the elemental content for the secondary phases within α-Cu matrix. Although nickel has a high solubility in copper, nickel silicide (Ni_2Si) formation occurs in the α-copper matrix due to the partial solubility of silicon. By considering the partial solubility of chromium in copper, the formation of chromium-rich silicides (Cr_3Si) is inevitable. It is known that chromium-rich silicides tend to form at grain boundaries due to segregation during the crystallization of the alloy. With the decreasing temperature during crystallization, nucleation of nickel silicide, another silicide, occurs in the α-copper matrix. The formation of such a precipitate and especially its tendency to reprecipitate from the aging process can be decisive in the final properties of Corson alloys. The XRD spectra given in Figure 2 indicates the presence of the mentioned silicides in the α-Cu matrix. The spectra also indicate dimensional changes in sharp α-Cu peaks due to cryogenic treatment and subsequent deformation. Following the solution annealing, more effective cooling can provide a significant structural change in the supersaturated α-Cu matrix. It is possible to obtain an even more supercooled copper matrix by cryogenic cooling, in which case a significant increase in lattice distortions can be observed. On the other hand, with the cold deformation, a significant change in the crystallite size, microstrain level and dislocation density of the alloy naturally occurs. Table 1 lists the changes in these structural properties for each condition of the alloy.

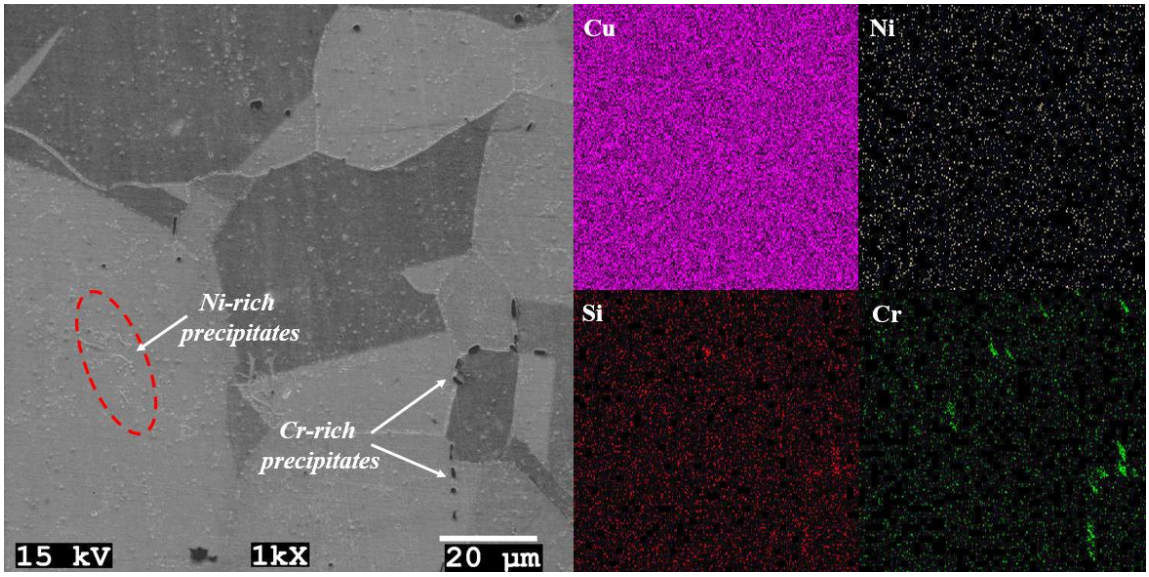

Figure 1. SEM image showing the microstructural features of $CuNi_3SiCr$ alloy and its EDS-mapping.

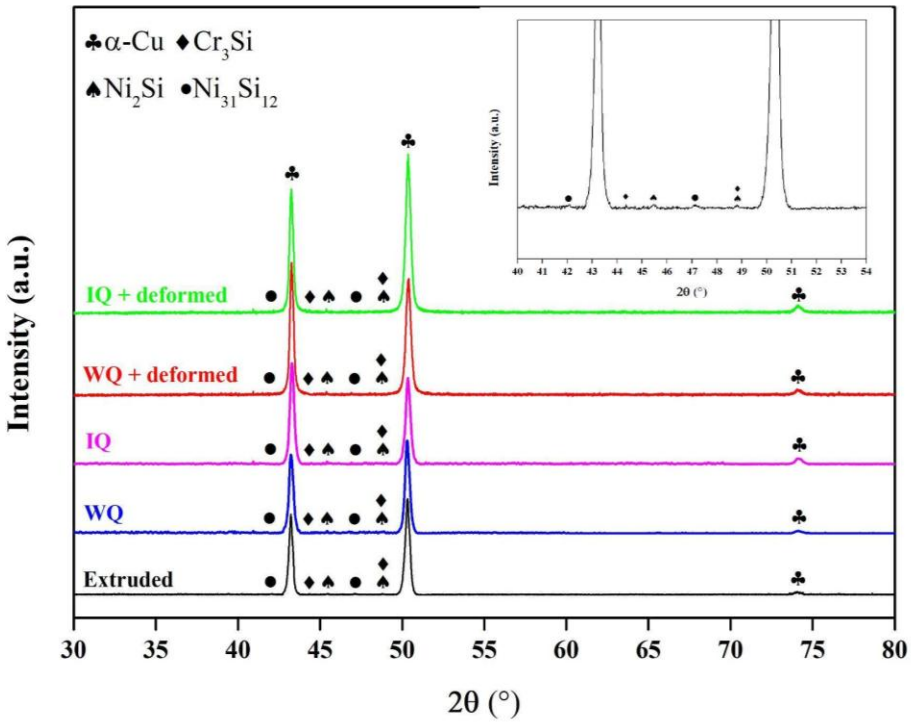

Figure 2. XRD spectra of the studied alloys.

Table 1. Calculated crystallite size, microstrain and dislocation density values depending on the condition.

Material	Crystallite size (D, nm)	Microstrain ($\varepsilon * 10^{-3}$)	Dislocation density ($\rho * 10^{-3}$, nm^{-2})
Extruded	23.56	3.45	1.72
WQ	23.66	3.44	1.79
IQ	23.62	3.46	1.82
WQ + deformed	22.67	3.59	1.95
IQ + deformed	22.30	3.65	2.01

By considering the calculated values given in Table 1, it is clear that the quenching condition causes a noticeable change in microstrain and dislocation density, although it does not cause a significant change in crystallite size. The higher quenching efficiency in dry ice environment caused an increase in microstrain and dislocation density. By cryogenic cooling, it is possible to reveal a higher level of lattice distortion and increase the potential for the formation of lattice defects such as dislocations. As it is well-known that deformation has a direct effect on the reduction of crystallite size. Such a reducing effect can be observed from the matrix data deformed following quenching and listed in Table 1. In particular, a significant decrease in crystallite size occurs with deformation in the copper-based material cooled in a dry ice environment compared to the extruded alloy. On the other hand, an increase in microstrain level and dislocation density is inevitable due to the deformation effect. From this perspective, it is clear how effective cooling in a dry ice environment is in increasing both structural components.

Within the scope of the study, EBSD studies are also carried out and the change in deformation capabilities of the alloys cooled in variable environments is monitored in response to the equivalent deformation. As can be seen from Figure 3, the recrystallization value could not be determined since no annealing/aging process is performed for the WQ and IQ conditioned alloys. However, after quenching in water, a significant amount of substructure is present in the alloy matrix. It is a fact that the shape and the orientation of the initial grains change according to the applied strain during deformation. In this process, the change of crystallographic orientation, the emergence of complex deformation modes and the formation of substructure are inevitable. While such a substructure formation tendency is observed with quenching in water, this process is not observed with deformation after quenching in dry ice environment. Quenching in dry ice promotes the formation of a highly supersaturated solid solution, thus inevitably resulting in higher levels of deformation (98.4 %) compared to the water quenching matrix (82.6 %). GOS maps also indicate that the relative increase in grain orientation tendency occurred after cold deformation of the quenched matrix in the dry ice environment (Figure 4).

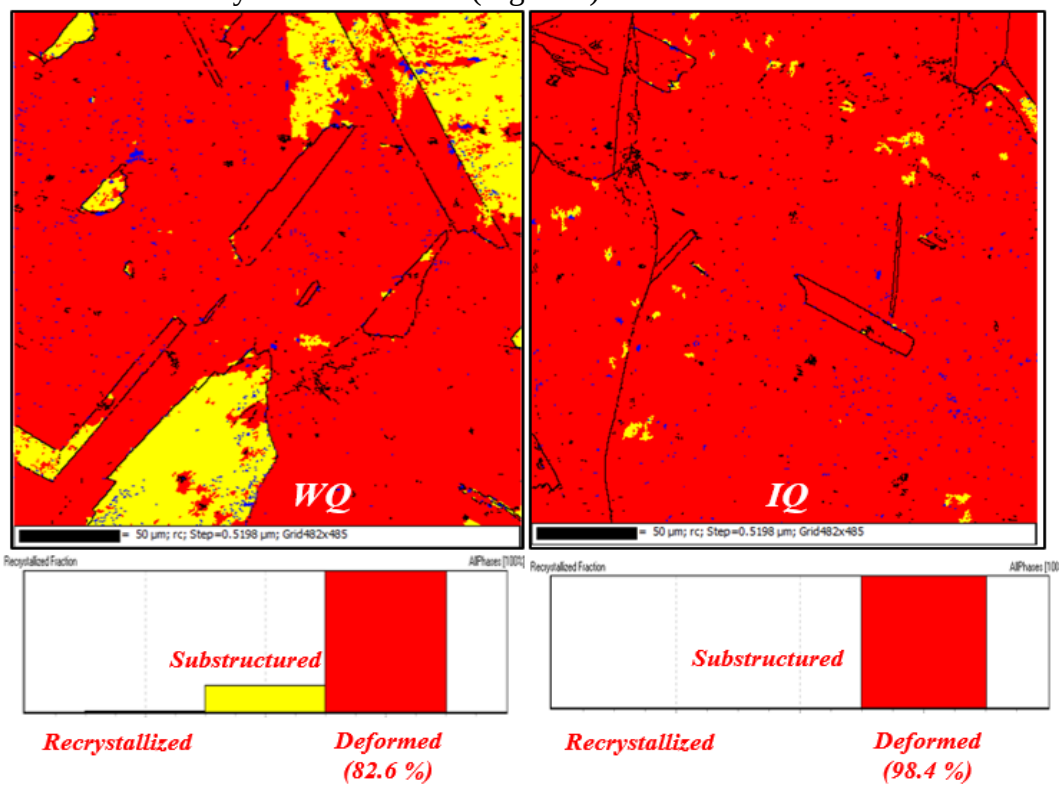

Figure 3. EBSD data of the alloys cooled in variable environment.

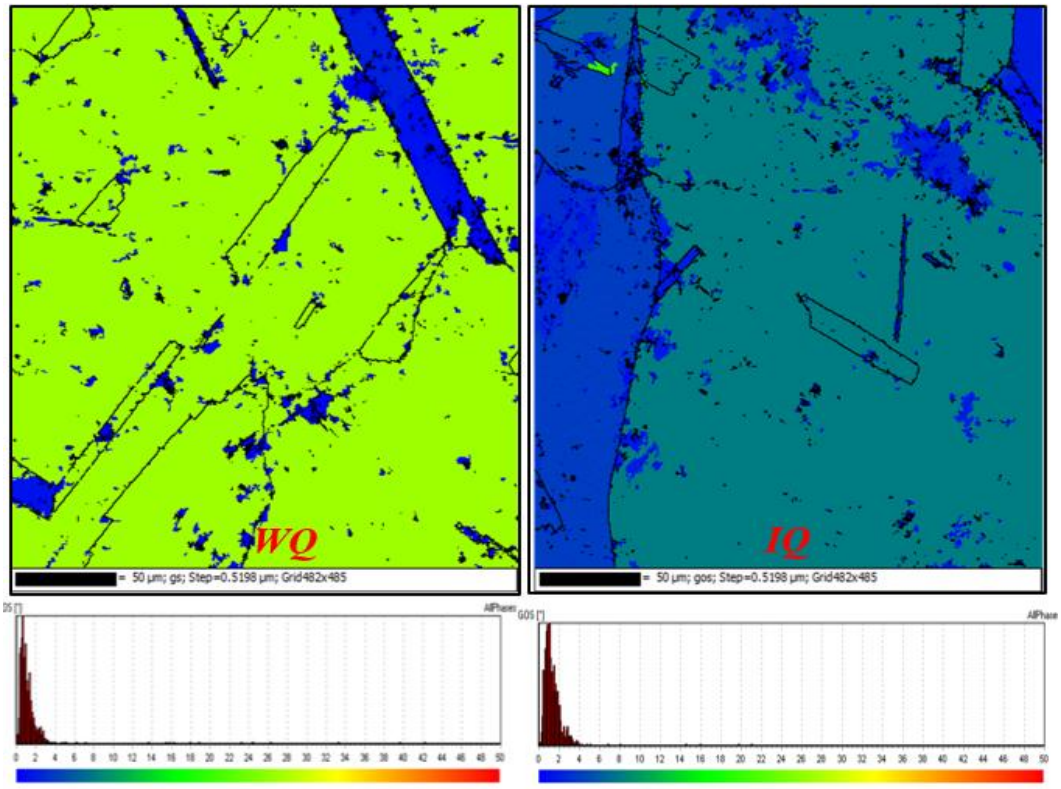

Figure 4. EBSD GOS maps of the alloys cooled in variable environment.

The changes in the properties of the alloys depending on the condition are listed in Table 2. The extruded alloy containing dense and finely dispersed metal silicide has the highest hardness value (215 HV1). In this condition, the electrical conductivity value of the alloy is determined as ~ 26 MS/m. It is inevitable that there will be a decrease in hardness and conductivity values depending on the degree of supersaturation after quenching. There is a significant decrease in hardness and conductivity values compared to the water quenching condition due to the provision of a greater supersaturation than in the dry ice environment. However, with cold deformation after quenching, changes may occur in both properties in a process that works inversely to each other. In a matrix with increased deformation capability, higher strains are expected to be obtained, the dislocation density increases and thus the hardness increases significantly. This entire process causes a detrimental effect on the electrical conductivity of the material, and the electrical conductivity value may decrease, especially due to increased microstrain and dislocation density.

Table 2. Properties of the alloy depending on the condition.

Material	Hardness (HV1)	Electrical conductivity (MS/m)
Extruded	215.5±9.2	25.83±0.13
WQ	94.2±8.9	12.68±0.11
IQ	84.6±9.4	12.10±0.11
WQ + deformed	105.3±6.1	12.03±0.12
IQ + deformed	113.8±9.8	11.58±0.10

4. Conclusion

Within the scope of this study, the effects of variable quenching conditions and deformation on the structural properties of a commercial $CuNi_3SiCr$ alloy are investigated. The highest hardness (215 HV1) and electrical conductivity (26 MS/m) values are observed in the extruded alloy containing dense metal silicide in its copper-based matrix. It is possible to reach values above these properties by deforming and aging this oversaturated and deformed matrix by rapid cooling after the solution annealing. In terms of the synergistic effect of the quenching medium and deformation, changes in crystallite size, microstrain and dislocation density depending on the condition are observed in the alloys, and it is determined that it would be possible to obtain matrices with lower crystallite size, higher microstrain and dislocation density compared to the extruded alloy, and accordingly, copper-based materials with high hardness, especially if a 30% cold deformation is applied following quenching in a dry ice medium. It is clear that in this type of formation, an increase in dislocation density in particular may make a significant contribution to the increase in precipitation kinetics during aging. However, an increase in the tendency of the alloy to recrystallize is also inevitable. The fact that the internal energy stored during deformation is a driving force for the recrystallization process reveals how important the combined effect of quenching and deformation is. The study results will enable the determination of processes for postponing recrystallization as well as monitoring the property changes in the material at the next aging stage.

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AERODYNAMIC PERFORMANCE ENHANCEMENT OF THE NACA 6412 AIRFOIL USING PLAIN FLAP AND SLOTTED FLAP CONFIGURATIONS

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ABSTRACT
Flap systems are developed to optimize the aerodynamic characteristics of airfoils, thereby significantly enhancing flight safety and improving operational performance. Since real flight conditions typically correspond to high Reynolds number regimes, high-lift devices such as plain flaps and slotted flaps are especially critical in these flow conditions. This study aims to investigate the aerodynamic effects of plain flap and slotted flap configurations on the NACA 6412 airfoil at high Reynolds numbers. In this context, the coordinates of the NACA 6412 airfoil were obtained from the Airfoil Tools database and used to generate a two-dimensional airfoil geometry via ANSYS DesignModeler. The geometries of the plain flap and slotted flap configurations were modeled in ANSYS SpaceClaim. The numerical study was carried out in ANSYS Fluent program. For each configuration, a computational flow domain was created to correspond to high Reynolds number conditions, and the numerical analyses were conducted accordingly. The angle of attack was varied between -8° and 10°, and appropriate freestream velocities were defined for each angle to compute the resulting aerodynamic forces in detail. The analysis results clearly indicate that both plain flap and slotted flap configurations provide significantly higher lift coefficients (C_L) compared to the baseline NACA 6412 airfoil. In particular, the slotted flap configuration led to a substantial increase in the C_L value. Due to the ability of the slotted flap to delay boundary layer separation, a more stable and effective flow structure was achieved under high Reynolds number and turbulent flow conditions. Based on these findings, it is concluded that the slotted flap configuration offers considerable aerodynamic advantages, especially during critical operational phases such as takeoff and landing.

Keywords: Lift Coefficient, Plain Flap, Slotted Flap, NACA 6412

Introduction

During flight, aircraft operate under varying aerodynamic conditions due to specific operational requirements and performance demands. Therefore, aircraft airfoils are designed to ensure optimal performance across a range of angles of attack and flight speeds, and must possess structural features that accommodate different aerodynamic load conditions [1,2]. High-lift devices used in aircraft are components or mechanisms integrated into the airfoil structure to enhance the lift generated by the airfoil [3]. High-lift systems, which have held a significant role in airfoil design throughout aviation history, optimize climb maneuvering capability and ensure safe approach speeds during takeoff and landing phases, thereby adapting takeoff and landing distances to airport operational constraints [4]. In addition, they are effectively utilized to enhance aircraft performance with the aim of improving cruise efficiency [5].

During take-off and landing maneuvers, continuous variations in speed, altitude, and flow conditions have a direct impact on boundary layer development and the aerodynamic characteristics of the flow [6]. In the take-off phase, under a given flap configuration and assuming a constant thrust-to-weight ratio, the rate of climb is dependent on the lift-to-drag ratio (L/D). Therefore, the aerodynamic efficiency of take-off and landing configurations should be designed to achieve an optimal balance in terms of C_L and L/D ratio [7].

Trailing-edge flaps increase the maximum lift coefficient ($C_{L,max}$) of an airfoil by enhancing its camber, while simultaneously reducing the stall angle of attack (α_{stall}), thereby enabling the airfoil to achieve a given lift coefficient at lower angles of attack. As illustrated in Figure 1, the angle of attack is defined as the angle between the airfoil's chord line and the free-stream airflow. When this angle exceeds a certain threshold, flow separation occurs, resulting in a sudden and significant decrease in the lift generated by the airfoil—an event known as stall. Trailing-edge flaps are categorized into various types based on their design and functionality, including: Split flap, plain flap, simple slotted flap, single-slotted fowler flap, fixed vane/main double-slotted flap, articulating vane/main double-slotted flap, and main/aft double-slotted flap [8].

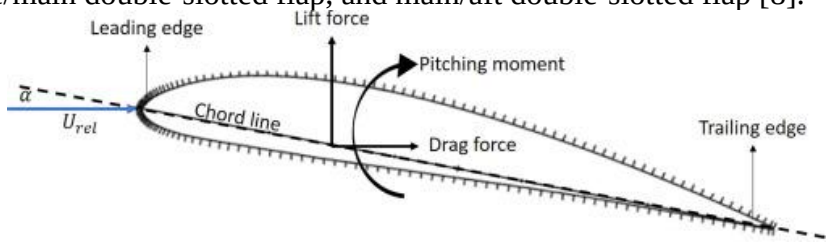


Figure 1. Forces and moments on airfoil [9]

Kanazaki et al. [10] conducted a multi-objective design study based on the Kriging model to investigate the aerodynamic optimization of an airfoil with slats and flaps (Reynolds number = 1.24×10^7). The findings show that the positioning of the slats and flaps is a determining factor for aerodynamic efficiency. Fowler [11] scientifically investigated the aerodynamic behavior and operating principles of single and multi-slot trailing-edge systems and established a basic theoretical framework in this field. This work has been an important milestone in the understanding and development of mechanisms to increase lift. Wild [12] conducted a comprehensive research on increasing the lift coefficient in airfoils equipped with active control mechanisms. In the study, he investigated the effects of gurney flap, one of the elements that provide high lift performance, on different wing configurations at angles of attack ranging from 0° to 12°. The findings revealed that the gurney flap optimizes aerodynamic efficiency by significantly increasing the lift coefficient in this angle range. Niu et al. [13] performed aerodynamic optimization of a trailing-edge structure

with variable hump by synchronously controlling the flaps and spoiler. The study showed that by minimizing the drag components such as wave drag and form drag, flight efficiency can be significantly improved over a wide range of lift coefficients. Velkova and Todorov [14] studied in detail the aerodynamic behavior of the slotted flap in the NACA-23012 air profile with a Reynolds number of 3×10^6. In their study, they focused on improving the aerodynamic performance by optimizing the position of the slotted flap. Rudolph [15] evaluated the aerodynamic performance of high-lift systems by experimentally and analytically investigating a landing configuration with slats and flaps. In the study, the recurrence of small-scale turbulence structures was detected and turbulence intrusion into the inner region of the slats was found to be predictable. Furthermore, the design characteristics of trailing-edge flap mechanisms are discussed and it is shown that fowler-type flap motion increases the lift coefficient by increasing the effective wing area and hump. The study highlights the impact of flap mechanisms on aerodynamic efficiency, structural design and aircraft weight, highlighting them as a critical component in the optimization of high-lift systems. Hussein et al [16] investigated the effect of different flap cord length, gap and overlap values on aerodynamic performance for the NACA 24012 airfoil. The results show that larger flap chord increases the lift coefficient but leads to drag penalty. The flap spacing for optimum lift was determined to be 1C% and the CFD model was validated with experimental data. Parluhutan [17] conducted the effect of flat flaps on lift and drag coefficients in NACA 0015 airfoil. The addition of flaps at 15° and 30° deflection angles increased the maximum lift coefficient to 1.5 and 1.71, respectively. However, this increased the drag coefficient by 65% and 178%, respectively. Salam et al. [18] investigated the effect of flap angle configuration of Swayasa airfoil on pressure coefficient (C_p) and flow separation. Experimental and CFD analyses for NACA 23012 airfoil at different main flap (F_u) and control flap (F_k) angles revealed similar flow patterns. At positive F_u angles, an increase in pressure at the bottom surface, a pressure drop at the top surface and higher turbulence formation in the flap regions were observed. Khan et al [19] conducted by CFD how the gurney flap improves the aerodynamic efficiency of the NACA 2412 airfoil. The simulation results showed that the gurney flap increased the lift by 28% while improving the lift/drag ratio by 22.05%. These findings revealed that the gurney flap is an effective method to improve the performance of the airfoil. Steenwijk & Druetta [20] studied CFD simulations for the NACA 0012 airfoil and investigated the effects of slotted flap and wingtip. The addition of the flap increased the lift and drag coefficients, while the addition of the airfoil tip decreased the lift coefficient. No difference was observed between isothermal and non-isothermal models and the results obtained were consistent with the wing theory. Anılır & Kurtuluş [21] performed two-dimensional, time-independent reynolds-averaged navier-stokes simulations for various angles of attack for takeoff, cruise and landing conditions on the SD7062 airfoil using a 0.30c single slotted flap. The highest lift coefficient was found to be 3.302 at $\alpha = 14°$ in the landing condition with 35° flap deflection. Shahrokhi et al. [22] investigated a double slotted morphed flap design that reduces drag and increases lift. Simulation results showed that the lift coefficient increased by 82% with 30° flap deflection in the NACA 4412 airfoil. It was also found that this design provided 14% higher maximum lift coefficient compared to the split flap at 60° deflection angle. Arra et al. [23] aimed to determine the best configuration by optimizing high lift devices. 2D CFD analysis with SolidWorks Flow Simulation showed that the optimized NACA 2412 three-element airfoil provides high aerodynamic performance.

In this study, the aerodynamic behavior of the NACA 6412 airfoil with the addition of a plain flap and slotted flap is investigated. First, the NACA 6412 coordinates obtained from the UIUC Airfoil Coordinates Database [24] were converted into a two-dimensional airfoil using

ANSYS Design Modeler. Then, a flow field was designed around the airfoil with a Reynolds number of 2,260,000. The angle of attack range investigated was between -8° and 10°, and the aerodynamic forces were analyzed by applying appropriate velocity values for each angle.

Material and Method

Numerical solutions are carried out by means of the following equations for 2D incompressible flow with the laws of continuity and conservation of momentum [24].

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \quad (1)$$

$$\rho\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right)=-\frac{\partial p}{\partial x}+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right) \quad (2)$$

$$\rho\left(u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}\right)=-\frac{\partial p}{\partial x}+\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right) \quad (3)$$

The k-ω SST model is preferred as the turbulence model. This model was chosen because it can predict boundary layer separations and flow structure more accurately [25]. The equations used are given below:

Turbulence kinetic energy (k) equation [26]:

$$\frac{\partial}{\partial t}(\rho k)+\frac{\partial}{\partial x_i}(\rho k u_i)=\frac{\partial}{\partial x_j}\left(\Gamma_k\frac{\partial k}{\partial x_j}\right)+\tilde{G}_k-Y_k+S_k \quad (4)$$

$$\frac{\partial}{\partial t}(\rho w)+\frac{\partial}{\partial x_i}(\rho w u_i)=\frac{\partial}{\partial x_j}\left(\Gamma_w\frac{\partial w}{\partial x_j}\right)+\tilde{G}_w-Y_w+S_w+D_w \quad (5)$$

In these equations, G_k represents the generation of turbulence kinetic energy due to mean velocity gradients, Γ_k represents the generation of w, Γ_w represent the effective diffusivity of k and w, respectively, Y_k and Y_w represent the dissipation of k and w due to turbulence. D_w represents the cross-diffusion term, S_k and S_w are user-defined source terms.

As a result of numerical solutions, the lift coefficient is found with the help of the following equations [27].

Coefficient of lift (C_L):

$$C_L=\frac{2L}{\rho {V_\infty}^2 A} \quad (6)$$

where L is the chord length, ρ is the density, V_∞ is the flow velocity and A is the area.

CFD Model

In the first step of model development, the NACA 6412 coordinates were converted into a two-dimensional airfoil geometry using ANSYS DesignModeler. For both the plain flap and slotted flap configurations, a flap deflection angle of 20° was selected. The new coordinates for the flaps were generated using the QBlade program, and the two-dimensional designs were created in ANSYS DesignModeler. The slotted flap configuration was modeled using ANSYS SpaceClaim. The final forms of all airfoil configurations are presented in Figure 2.

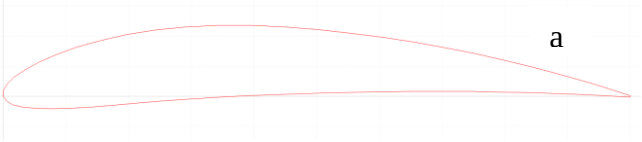


Figure 2. Created geometries: a) Naca 6412 b) Plain Flap c) Slotted Flap

Computational Fluid Dynamics (CFD) analyses were conducted using the ANSYS Fluent software. The flow domain was defined such that the outer boundaries were sufficiently distant from the airfoil profile. As illustrated in Figure 3, the boundary conditions were specified as a velocity inlet at the inlet, a pressure outlet at the outlet, and a no-slip wall condition on the airfoil surface.

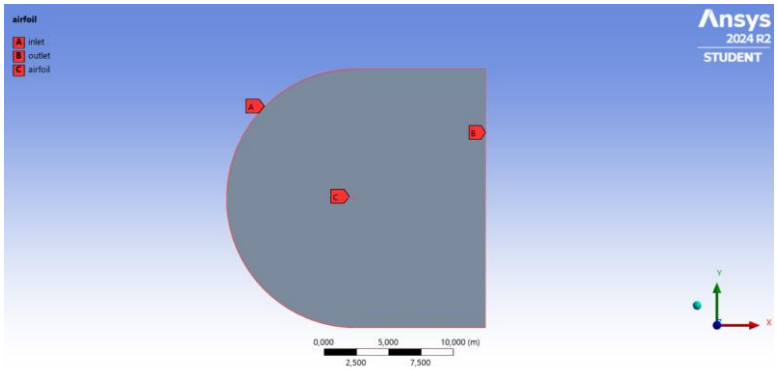


Figure 3. Representation of boundary conditions

A mesh independence study was conducted to investigate the effect of mesh structure on the results. When examining the variation of the lift coefficient with increasing mesh density, values of 0.442, 0.576, and 0.579 were obtained for mesh sizes of 217,385, 312,356, and 486,512 elements, respectively. As a result of the mesh independence study, the optimum mesh size was determined to be 312,356 elements, as illustrated in Figure 4, and this mesh structure was adopted for the analyses.

In terms of solver settings, a density-based solver was employed. The flow was modeled as steady and incompressible, and solutions were obtained within the subsonic regime. Temporal discretization was performed with second-order accuracy, while spatial discretization was carried out using the SIMPLE algorithm. A convergence criterion with a residual tolerance of 10^{-6} was applied.

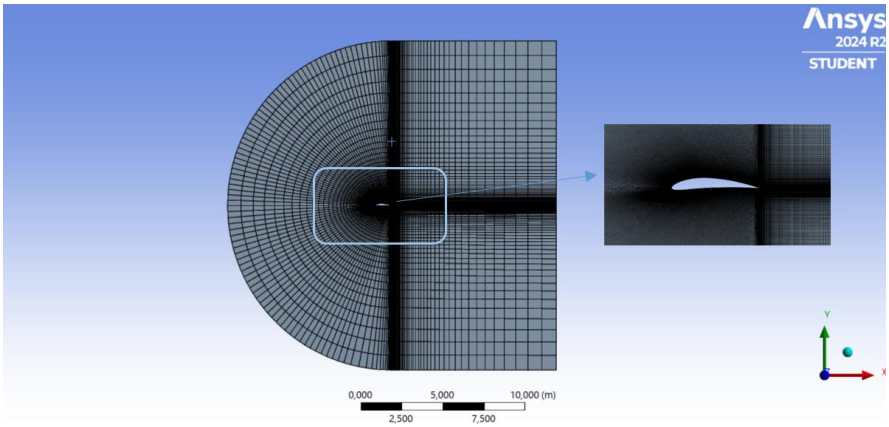


Figure 4. Mesh structure

Validation

As part of the validation studies, the obtained lift coefficient values were compared with the experimental results for the NACA 6412 airfoil obtained from the NASA database [28]. A comparison of the experimental and CFD (this sudy) results is presented in Figure 5. A high level of agreement was observed between the results of the present study and the experimental data.

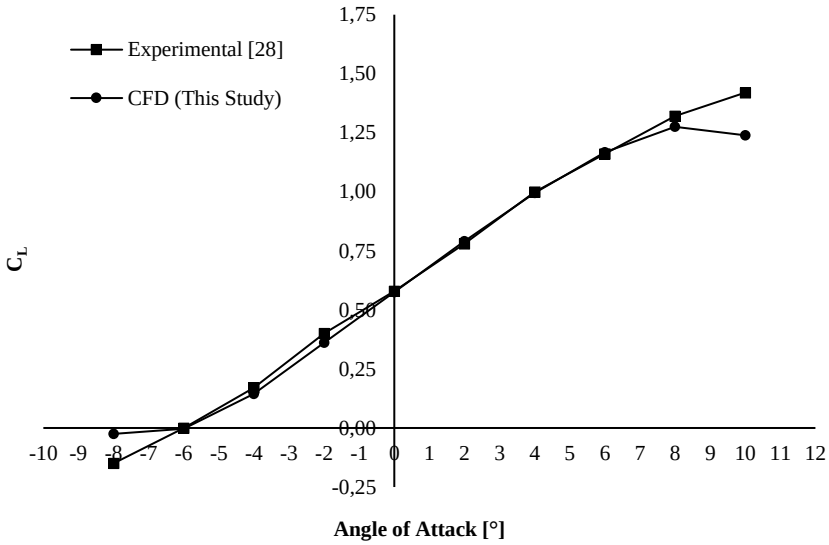


Figure 5. Comparison of experimental data and CFD results of C_L values depending on the angle of attack for Naca 6412

Conclusion

Figure 6 presents the lift coefficient values as a function of the angle of attack for the plain flap and slotted flap configurations applied to the NACA 6412 airfoil. It is observed that both flap configurations generate higher lift compared to the standard airfoil. Moreover, the slotted flap demonstrates superior performance over the plain flap across the examined range of attack angles.

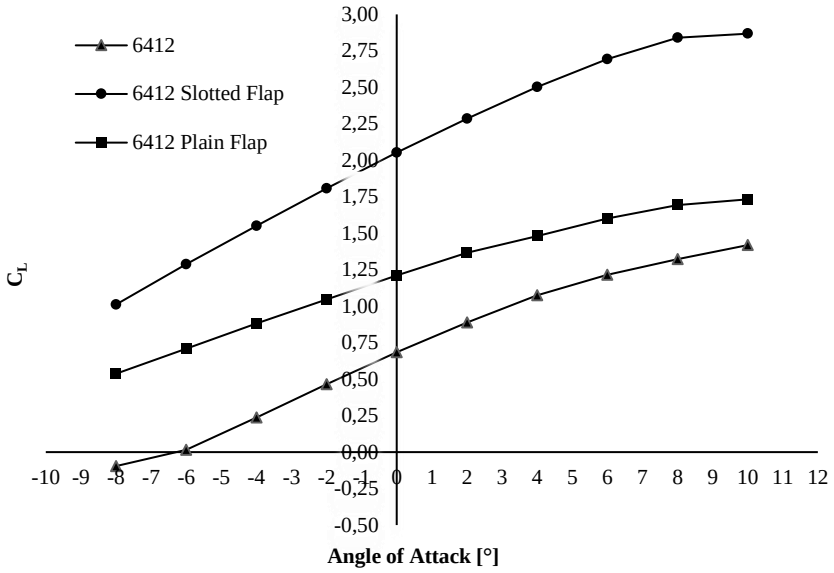
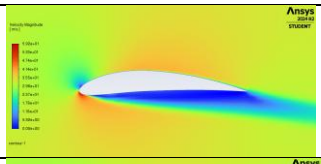
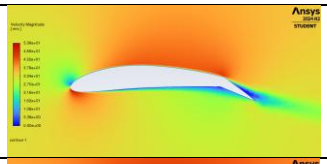
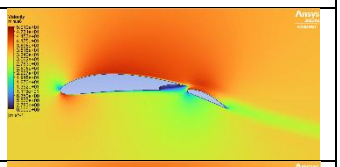
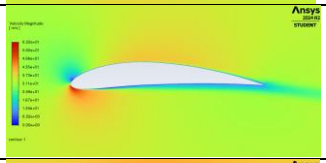
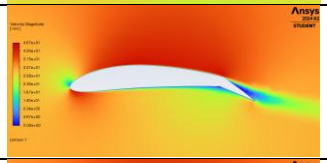
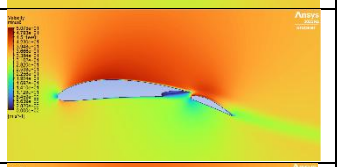
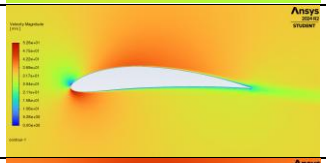
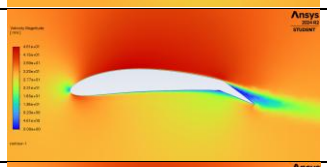
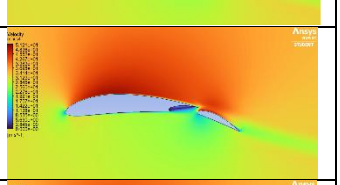
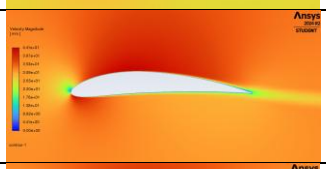
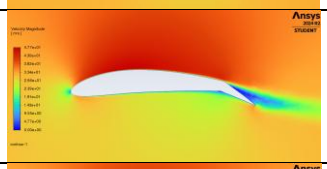
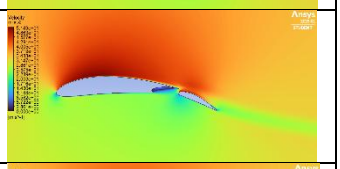
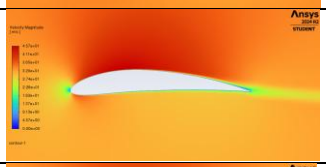
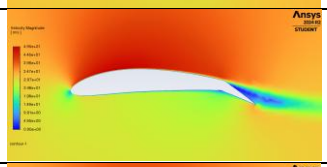
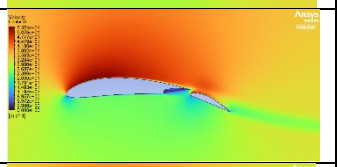
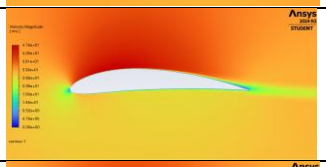
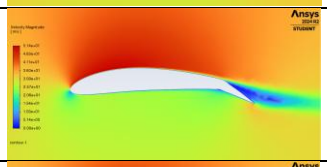
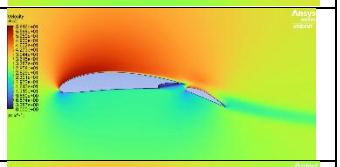
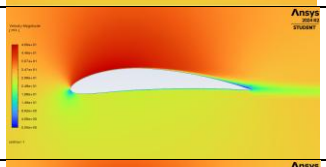
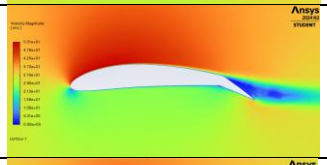
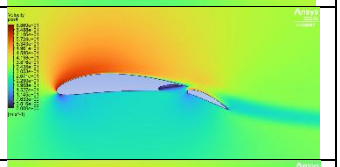
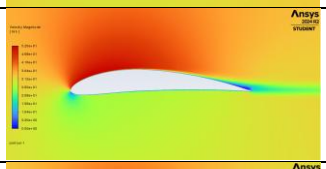
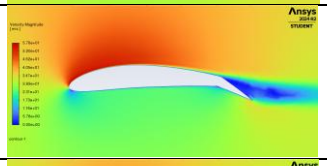
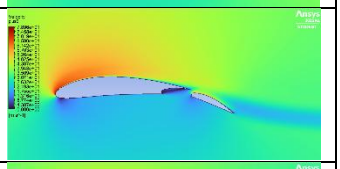
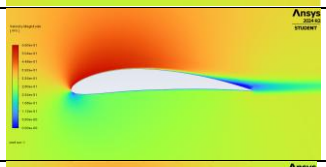
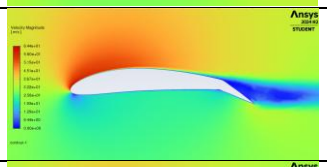
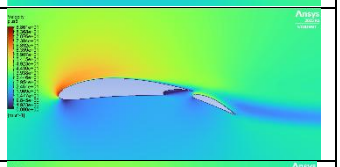
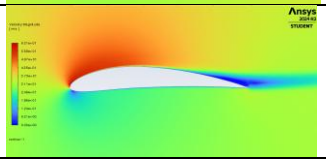
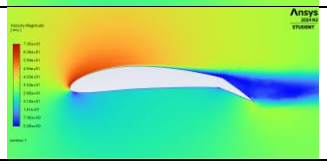
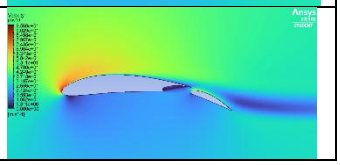


Figure 6. C_L variation with angle of attack for all configurations

The lift coefficient for the standard NACA 6412 airfoil increased smoothly with the angle of attack from -8° to 10°. The C_L value, which was approximately -0.15 at -8°, increased to around 1.45 at 10°. This indicates the airfoil's natural lift production and its increased sensitivity to positive angles of attack due to its asymmetric design. The plain flap configuration provided higher C_L values for all angles of attack compared to the standard airfoil. At -8°, the C_L was approximately 0.55, and at 10°, it was around 1.75. However, since the plain flap did not delay boundary layer separation, the C_L increase remained more limited compared to the slotted flap. The highest C_L values were observed for the slotted flap configuration. At 8°, the C_L was around 1.05, and at 10°, it reached approximately 2.9. The slotted flap, by accelerating the flow over the upper surface through the slot structure, effectively delayed flow separation, providing a significant contribution, especially at higher angles of attack. Moreover, the slotted flap configuration demonstrated a sharper rise in the C_L curve, leading to a more substantial increase in lift. As the slotted flap not only enhanced the flap effect but also provided flow control, it significantly improved the aerodynamic performance.

The variation of velocity contours with respect to angle of attack for different airfoil configurations is presented in Table 1. For the standard NACA 6412 airfoil, the flow remains largely attached over the upper surface between attack angles of -8° and 10°. Although a slight tendency toward flow separation is observed at -8°, the overall flow pattern appears to be closer to symmetric. In the case of the plain flap configuration, while positive lift generation begins within the same range of angles, its effectiveness remains limited at lower angles. For the slotted flap configuration, the presence of the slot enables the flow to stay more attached along the upper surface.

Table 1. Representation of velocity contours according to angles of attack

Angle of Attack (°)	6412	6412 with plain flap	6412 with slotted flap
-8			
-6			
-4			
-2			
0			
2			
4			
6			
8			
10			

When examining the velocity contours for angles of attack between 2° and 6°, it was observed that the flow over the standard NACA 6412 airfoil remained attached, with a noticeable acceleration over the upper surface. In the plain flap configuration, a slight tendency toward flow separation was detected on the upper surface. For these angle values, the slotted flap configuration exhibited the most uniform and continuous flow. Due to the jet effect generated by the slot, the flow acceleration over the upper surface increased, and no flow separation was observed.

For angles of attack between 8° and 10°, flow separation began to occur on the upper surface of the standard NACA 6412 airfoil. In the plain flap configuration, separation initiated earlier and was more pronounced, as the presence of the flap disturbed the flow direction. This confirms the decreasing slope in the graph as the C_L increase is about to slow down. In the slotted flap configuration, the flow remained attached to the upper surface, with the strong influence of the slot effect still clearly evident. The slotted flap delays flow separation on the upper surface by supplying high-energy air through the slot, thereby maintaining controlled flow even at higher angles of attack. This behavior demonstrates that slotted flaps effectively delay stall and confirms the performance enhancement described in the literature [29].

In future studies, the effects of varying flap deflection angles, slot opening widths, and flap length ratios on performance will be systematically analyzed. Additionally, the impact of these configurations on not only lift but also drag coefficient and moment behavior will be examined, with the aim of providing a comprehensive aerodynamic assessment.

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TUZ STRESİNİN BAZI SORGUM (*Sorghum bicolor* L.) ÇEŞİTLERİNDE ÇİMLENME FİZYOLOJİSİNE ETKİLERİ

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ÖZET
Sorgum (*Sorghum bicolor* L., Fam: Poaceae), kuraklık ve yüksek sıcaklık gibi zorlu çevre koşullarına yüksek toleransı bulunan tahıl bitkisidir. Gıda, yem ve biyoyakıt üretimi gibi geniş yelpazede kullanımı sayesinde ekonomik değeri yüksek olan bu bitki, iklim değişikliğine bağlı olarak artan çevresel stres faktörlerine karşı sürdürülebilir tarım açısından son yıllarda önemli bir alternatif oluşturmaktadır. Tarımsal alanlarda yaygın olarak karşılaşılan tuzluluk, bitki büyümesini olumsuz etkileyerek verim kayıplarına yol açmakta ve sorgumda da gelişim parametrelerinde düşüşe neden olabilmektedir. Abiyotik stres faktörlerinden olan tuzluluk, toprakta çözünen Na^+ ve Cl^- iyonların birikmesi sonucu bitkide ozmotik dengeyi bozarak fizyolojik hasara yol açmakta ve iyonik ve ozmotik stresler gibi sekonder streslere neden olmaktadır. Bu çalışmada, sorgum bitkisinin 5 farklı çeşidinin (Akdarı, Aldarı, Gözde, Leoti ve Rox) tuzluluk stresi altında çimlenme fizyolojisindeki değişimin ortaya konulması amaçlanmıştır. Kontrollü koşullar altında bitki büyütme kabininde gerçekleştirilen petri deneylerinde tohumlar 10 gün boyunca tuzluluğa maruz bırakılarak günlük takip edilmiştir. Denemede uygulama grupları 0, 50, 100, 150, 200 ve 250 mM NaCl olacak şekilde belirlenmiştir. Tuzluluk uygulaması sonunda her bir birey fotoğraflanarak, sürgün ve kök boyları ölçülmüştür. Ardından sürgün ve köke ait yaş ve kuru ağırlıkları tartılmıştır. Ayrıca, çimlenme başarıları, tuz tolerans indeksleri ve çimlenme hızları da belirlenmiştir. Bu çalışma ile farklı sorgum çeşitlerinin optimum çimlenme şartları ve bu tohumların tuzluluğa dayanıklılıkları belirlenmiştir. Bu çalışmanın, ıslah çalışmalarına katkı sağlaması ve tarımsal üretimde oluşan verim kayıplarının önüne geçilebilmesi adına önem taşıdığı düşünülmektedir.
Anahtar kelimeler: Çimlenme, fizyoloji, stres, sorgum, tuzluluk

EFFECTS OF SALT STRESS ON GERMINATION PHYSIOLOGY OF SOME SORGHUM (*Sorghum bicholar* L.) VARIETIES

ABSTRACT

Sorghum (*Sorghum bicolor* L., Fam: Poaceae) is a cereal plant with high tolerance to harsh environmental conditions such as drought and high temperature. This plant, which has a high economic value thanks to its wide range of uses such as food, feed and biofuel production, has been an important alternative in terms of sustainable agriculture in recent years against increasing environmental stress factors due to climate change. Salinity, which is commonly encountered in agricultural areas, adversely affects plant growth, leading to yield losses and may cause a decrease in developmental parameters in sorghum. Salinity, which is one of the abiotic stress factors, causes physiological damage by disrupting the osmotic balance in the plant as a result of the accumulation of Na^+ and Cl^- ions dissolved in the soil and causes secondary stresses such as ionic and osmotic stresses. In this study, it was aimed to determine the changes in germination physiology of 5 different sorghum varieties (Akdarı, Aldarı, Gözde, Leoti and Rox) under salinity stress. In the petri experiments carried out in the plant growth cabinet under controlled conditions, the seeds were exposed to salinity for 10 days and monitored daily. In the experiment, treatment groups were determined as 0, 50, 100, 150, 200 and 250 mM NaCl. At the end of salinity treatment, each individual was photographed and shoot and root lengths were measured. Then, wet and dry weights of shoots and roots were weighed. Germination success, salt tolerance indices and germination rates were also determined. In this study, optimum germination conditions of different sorghum varieties and their tolerance to salinity were determined. It is thought that this study is important to contribute to breeding studies and to prevent yield losses in agricultural production.

Key words: Germination, physiology, stress, sorghum, salinity

1. GİRİŞ

Yoğun tarımsal faaliyetler su kaynaklarının aşırı kullanımına neden olmakta ve bu durum iklim değişikliğinin de etkisiyle sıcaklık, yağış, radyasyon ve rüzgarın da değişimi ile artarak tarımsal verimlilikte ve ürün kalitesinde önemli düşüşlere yol açmaktadır (Passioura, 2007). İklim değişikliği, çevresel stres faktörlerinin etkisini arttırarak bitkilerin fizyolojik ve metabolik süreçlerini olumsuz etkiler, gelişim ve verimlerini sınırlandırır (Hashem vd., 2018). Tarımsal alanlarda tuzluluk, özellikle kurak ve yarı kurak bölgelerde ciddi ekolojik ve tarımsal kayıplar meydana getiren başlıca çevresel etmenlerden biridir (Himabindu vd., 2016; Jia vd., 2019; Liu vd., 2020). Özellikle tarımsal üretimde iklim değişikliğinin sarsıcı etkileri eklendiğinde tuzluluğun rolü dikkat çekici boyutlara ulaşmıştır. Birleşmiş Milletler Gıda ve Tarım Örgütünün (FAO) 2024 yılı verilerine göre, dünyada tuzluluğa maruz kalan toprak alanları yaklaşık 1381 milyon hektar olup, bu miktarın küresel kara yüzeyinin %10,7'sine karşılık geldiği raporlanmıştır. Toprakta tuzluluk, yalnızca çözünebilen tuzların birikimiyle değil; aynı zamanda yetersiz drenaj, aşırı ve bilinçsiz sulama, yüksek buharlaşma oranları ile meteorolojik ve jeolojik dalgalanmalar gibi çeşitli çevresel ve antropojenik etkenlerle ilişkilidir (Kiremit vd., 2017). Tuzluluk düzeyinin artmasıyla birlikte ortaya çıkan iyon toksisitesi, bitkilerin su ve mineral alımını sınırlandırarak toprak yapısını bozmakta ve bitkisel uyum mekanizmalarında fizyolojik hasara yol açmaktadır (Isayenkov, 2012; Litalien ve Zeeb, 2020; Balasubramaniam vd., 2023). Ayrıca, bitkilerde yaprak yaşlanmasını hızlandırmakta ve enzim aktivitelerini bozarak fotosentez ile solunum gibi temel metabolik süreçlerin aksamasına da yol açmaktadır. Bu fizyolojik aksamalar, reaktif oksijen türlerinin birikmesine neden olarak hücresel yapılarla birlikte organel ve membran bütünlüğünü de olumsuz etkilemektedir (Sachdev vd., 2021). Özellikle tahıl grubu bitkilerde tuz stresi; büyüme, gelişme ve verim üzerinde önemli kayıplara yol açarak tarımsal üretim açısından ciddi tehditler oluşturur (Kiremit vd., 2017).

Sorgum (*Sorghum bicolor* L.), tahıl bitkileri arasında dünyada tarımı yapılan beşinci bitki olup tuz toleransı yüksektir (Arouna vd., 2020; Espitia-Hernández vd., 2020; Rashwan, vd., 2021). Poaceae familyasının bir üyesi olan sorgum, Asya ve Afrika başta olmak üzere kurak ve yarı kurak bölgelerde temel gıda kaynağıdır (Balole ve Legwaila., 2006; Dehnavi vd., 2020). Ayrıca, genellikle hayvan yemi olarak kullanılsa da glutensiz yapısı nedeniyle insan beslenmesinde alternatif bir ürün olarak kullanım alanı giderek artmaktadır (Aggarwal vd., 2017). Tek yıllık sıcak iklim bitkisi olan sorgum, kısa büyüme döngüsü, farklı çevresel şartlara adaptasyon yeteneği ve yüksek biyokütle verimiyle de önemli bir biyoyakıt kaynağıdır (Abu-Ellail vd., 2023). Diğer tahıllara kıyasla, demir bakımından zengin olup önemli miktarlarda magnezyum ve çinko ihtiva etmektedir (Kotla vd., 2019; Espitia-Hernández vd., 2020; Kimani vd., 2020). Ayrıca, sorgum taneleri fenolik asitler ve flavonoidler gibi polifenoller açısından da çeşitlilik barındırır (Punia vd., 2021).

Tuzluluk gibi elverişsiz koşullarda dahi tarımı mümkün olan sorgum, besin değeri yüksek ve uyum yeteneği gelişmiş bir tahıl olması sebebiyle sürdürülebilir tarım için önemli alternatiftir. Tuzlu topraklarda verimliliğini belirlemek amacıyla yapılan çimlenme deneyleri, uygun çeşitlerin seçilmesine ve tarımsal üretimin artırılmasına katkı sağlar. Hem gıda hem de biyoyakıt üretimi için stratejik bir bitki olması özelliğinden dolayı uygun olmayan şartlara dayanıklılığın belirlenmesi önemli konular arasında gelmektedir. Dolayısıyla sorgum bitkisinin verimini sınırlayan tuzluluk faktörünün meydana getirdiği değişimlerin araştırılması da önem arz etmektedir (Bilgici, 2021; Dewi vd., 2023; Kaur vd., 2023; Ahmed vd., 2024).

Bu çalışmada, önemli bir ikame tahıl olarak değerlendirilen sorgum bitkisinin tuz stresi altında gösterdiği çimlenme fizyolojisinin belirlenmesi hedeflenmiştir. Literatürde, özellikle tohum

çimlenmesi aşamasında sorgum üzerine yapılan çalışmaların yetersiz olması bu araştırmayı özgün kılmaktadır. Bu kapsamda, farklı konsantrasyonlarda (0, 50, 100, 150, 200 ve 250 mM NaCl) tuz stresine maruz bırakılan 5 farklı sorgum çeşitlerinde kök ve sürgün uzunlukları, yaş ve kuru ağırlıkları, çimlenme oranları, çimlenme hızları ve tuzluluk indeksleri belirlenerek çeşit düzeyinde tuz dayanıklılıkları ortaya konulmuştur.

2. MATERYAL ve YÖNTEM

2.1. Bitki Materyali ve Yetiştirme Koşulları

Çalışma, kontrollü koşullar altında bitki büyütme kabininde 24 °C sıcaklık ve %60-70 nem koşullarında gerçekleştirilmiştir. Denemede kullanılan sorgum (*Sorghum bicolor* L., Fam: Poaceae) tohumları, Batı Akdeniz Tarımsal Araştırma Enstitüsü Müdürlüğünden temin edilmiştir. Çalışmada Akdarı, Aldarı, Gözde, Leoti ve Rox çeşitleri kullanılmıştır. Ekim öncesinde tohumlar çamaşır suyunda 10 dakika süreyle dezenfekte edilmiş ve ardından saf su ile durulanarak ekime hazır hale getirilmiştir. Deneme, çift kat steril filtre kâğıdı yerleştirilmiş petri kaplarında, her uygulama için 20 biyolojik tekrarla gerçekleştirilmiştir. Her bir sorgum çeşidi için 6 farklı uygulama grubu, NaCl'nin 50, 100, 150, 200 ve 250 mM konsantrasyonları ve kontrol grubu olarak da saf su seçilerek oluşturulmuştur. Süre boyunca tohumların nemi kontrol edilerek uygulama gruplarına ait çözeltiler uygulanarak kurumamaları sağlanmıştır. 10 gün boyunca çimlenme günlük olarak takip edilmiş, günlük olarak çimlenme verileri kaydedilmiş ve sonunda çimlenen tohumlar fotoğraflanarak cetvel ile sürgün ve kök uzunlukları ölçülmüştür. Ardından, bitkilerin sürgün ve kök yaş ağırlıkları tartılmış ve 70 °C'de 72 saat süre ile etüvde kurutularak kuru ağırlıkları belirlenmiştir.

2.2. Çimlenme Oranı

Tohumların çimlenmesi günlük olarak takip edilerek radikulanın 0,2 cm çıkması çimlenme kriteri olarak kullanılmıştır. Çimlenme oranlarının karşılaştırılmasında 10. gün elde edilen çimlenme verileri kullanılmıştır. Buna göre çimlenme yüzdesi aşağıda verilen formülle belirlenmiştir.

ÇO = (G/T) *100

G: Çimlenen tohum sayısını, T: Kullanılan toplam tohum sayısı

2.3. Tuz Tolerans İndeksi

Tuz tolerans indeksinin belirlenmesinde 10. güne ait çimlenme verileri temel alınmıştır. Tuz tolerans indeksi aşağıda belirtilen formüle göre hesaplanmıştır.

TT= (A/B) *100

A: İşlem görmüş tohumlarda çimlenme, B: Kontrol grubunda çimlenme

2.4. Çimlenme Hızı

Çimlenme hızlarının belirlenmesinde günlük takip edilen veriler kullanılmıştır. Buna göre hız aşağıdaki formül yardımıyla hesaplanmıştır.

ÇH = N1/T1+N2/T2+…….+Nn/Tn

N: Çimlenen tohum sayısı, T: Çimlenmenin gerçekleştiği gün sayısı

2.5. İstatistiksel Analizler

Denemelerden elde edilen bulgular Tek Yönlü Varyans Analizi (One way ANOVA) ile analiz edilmiş ve ortalamalar arasındaki farklılıklar Duncan Testi ile belirlenmiştir. Uygulamalar arasındaki anlamlılık $p<0,05$ önem düzeyinde ortaya konulmuştur.

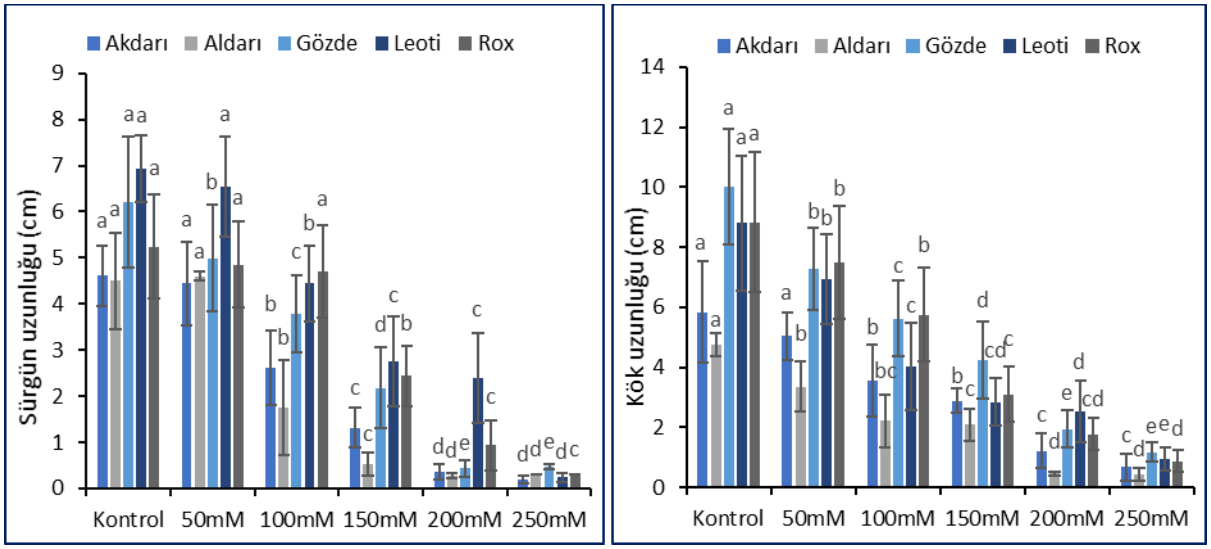
3. BULGULAR ve TARTIŞMA

Bitkiler, yaşamlarının erken gelişme evresinde tuzluluğa diğer dönemlere kıyasla daha duyarlıdır (Lal, 1985). Bu nedenle, erken dönemde tuzluluğa dayanıklı çeşitlerin seçilmesi, sağlıklı bir çıkış ve güçlü bir ilk gelişim sağlanarak toprak tuzluluğuna karşı alınabilecek en etkili önlemlerden biridir (Kökten vd., 2010). Bu çalışmada, sorgum çeşitleri üzerinde farklı tuz konsantrasyonlarının etkisini değerlendirmek amacıyla tohumlar çimlendirilmiştir ve erken gelişme döneminde tuzluluk stresine karşı tolerans gösteren çeşitlerin belirlenmesi hedeflenmiştir. Akdarı, Aldarı, Gözde, Leoti ve Rox çeşitleri, kontrol (saf su) grubuna ek olarak 50, 100, 150, 200 ve 250 mM NaCl konsantrasyonuna maruz bırakılmıştır. Sorgum çeşitlerinin artan tuzluluğa karşı morfolojik olarak meydana gelen değişimleri Şekil 1'de gösterilmektedir.

Şekil 1. Tuz stresine maruz bırakılan sorgum (*Sorghum bicolor* L.) çeşitlerinde morfolojik değişimler

Sürgün uzunluklarına dair sonuçlar Şekil 2'de gösterilmektedir. Akdarı çeşidinin sürgün uzunluklarında kontrol grubuyla kıyaslanan 50 mM NaCl uygulamasında istatistiksel olarak anlamlı fark oluşturmazken (p<0,05), 100, 150, 200 ve 250 mM NaCl konsantrasyonlarında sırasıyla %43, %71,6, %92,1 ve %96 oranında azalma kaydedilmiştir. Aldarı çeşidinde tuzluluk stresinin sürgün gelişimi üzerindeki etkileri değerlendirildiğinde, Akdarıda olduğu gibi 50 mM NaCl uygulamasında kontrol grubu ile sürgün boyu arasında istatistiksel olarak anlamlı bir fark saptanmamıştır (p<0,05). Ancak daha yüksek tuz konsantrasyonlarında, sürgün boylarında kontrol grubuna kıyasla, 200 ve 250 mM NaCl'de sırasıyla %94 ve %93,3 oranında azalma meydana gelmiştir. Gözde çeşidinde sürgün uzunluğu, kontrol ve uygulama grupları arasında kıyaslanmış, 50, 100, 150, 200 ve 250 mM NaCl uygulaması için sırasıyla %19,6, %39, %65, %93 ve %95,4 oranında azalma meydana gelmiştir. Gözde çeşidinde sürgün uzunluğunda meydana gelen azalmalar, tuz konsantrasyonundaki artışa paralel olarak bitki gelişiminin ciddi şekilde baskılanabildiğini göstermektedir. Leoti çeşidinin sürgün uzunlukları incelendiğinde, 50 mM NaCl uygulamasında kontrol grubuna kıyasla istatistiksel olarak anlamlı (p<0,05) bir fark oluşmazken en yüksek tuzluluk düzeyi olan 250mM NaCl'de ise %96,5 oranında azalma kaydedilmiştir. Rox çeşidinde ise sürgün uzunlukları, kontrol grubu ile karşılaştırıldığında, tuzluluk gruplarında 50 mM ve 100 mM NaCl uygulamalarında istatistiksel olarak anlamlı (p<0,05) bir fark gözlemlenmemiştir. Ancak 150, 200 ve 250 mM tuzlulukta sürgün uzunluğunda azalma meydana gelmiştir. Bu azalma, en yüksek düzeyde 200 ve 250 mM tuzlulukta sırasıyla %82 ve %94,2 olarak kaydedilmiştir (Şekil 2). Tuzluluk stresinin artmasıyla Rox çeşidinde sürgün boyunda azalmalar meydana gelmektedir (Parlak ve Özaslan Parlak, 2006). Tuz stresinin bitkilerde sürgün uzunluğuna olumsuz etkisinin olduğu pek çok araştırmada ifade edilmiştir (Öztürk vd., 2021; Özkan ve Demiroğlu Topçu, 2017; Vazirimehr vd., 2014; Jini ve Joseph, 2017). Artan tuz konsantrasyonlarının bitkide su alımını kısıtlaması ve iyon dengesini bozarak metabolik süreçleri aksatması, sürgün boyunda gözlenen azalmanın temel nedeni olabilir.

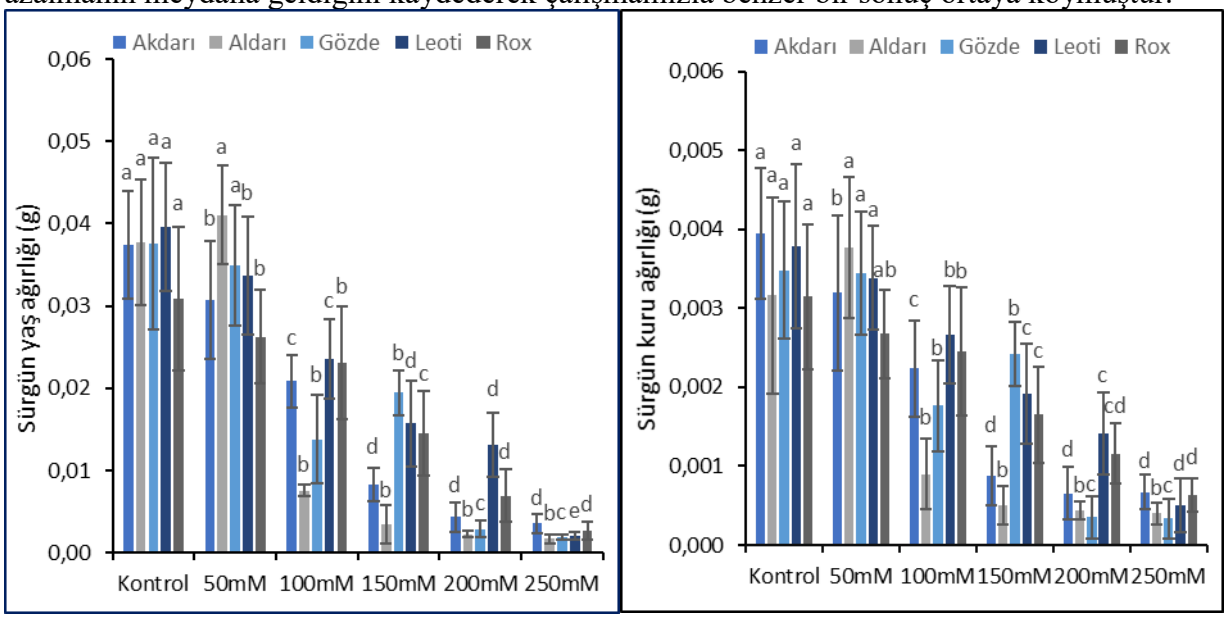
Kök uzunluğu üzerine tuz stresinin etkileri Şekil 2'de gösterilmiştir. Akdarıda kök uzunlukları, sürgün uzunluklarına benzer şekilde kontrol ve 50 mM NaCl uygulamaları arasında istatistiksel olarak anlamlı farklılık gözlenmemiş (p<0,05), ancak 250 mM NaCl uygulamasında %88,36 oranında önemli azalma meydana gelmiştir. Aldarı çeşidinde kök uzunluğu kontrolle kıyaslandığında tüm uygulama gruplarında anlamlı azalmalar meydana gelmiştir. Bu azalmalar 50, 100, 150, 200 ve 250 mM NaCl için sırasıyla %29,3, %53,3, %56, %90 ve %90,5 oranındadır. Tuzluluk artışına bağlı olarak kök uzunluğunda gözlenen azalmalar, tuz stresinin kök gelişimini erken aşamalardan itibaren baskıladığını göstermektedir. Gözde çeşidinin kök uzunluğu ise kontrolle kıyaslandığında uygulama grupları arasında en önemli azalma 250 mM NaCl'de %88 olarak kaydedilmiştir. Leoti çeşidinin kök uzunluğunda 50, 100, 150, 200 ve 250 mM tuzluluk seviyeleri kontrolle kıyaslandığında sırasıyla %25,4, %56, %69,4, %73 ve %91,2 oranında azalma meydana gelmiştir. Rox çeşidinde ise kontrolle kıyaslanan tüm uygulama gruplarında belirgin azalmalar görülmüş, en yüksek azalma Leoti çeşidinde olduğu gibi %88 olarak 250mM NaCl uygulamasında kaydedilmiştir.



Şekil 2. Tuz stresine maruz bırakılan sorgum çeşitlerinde sürgün ve kök uzunluğunda meydana gelen değişimler

Sürgün yaş ağırlıkları üzerine tuz stresinin etkileri Şekil 3'te gösterilmiştir. Akdarı sorgum çeşidinde sürgün yaş ağırlığı verileri değerlendirildiğinde, kontrol bitkilerine kıyasla uygulama grupları arasında 200 ve 250 mM NaCl uygulaması ile %99 azalış meydana gelmiştir. Aldarı uygulama grupları kontrol grubuyla kıyaslandığında, 50 mM tuzlulukta sürgün yaş ağırlıkları arasında istatistiksel olarak anlamlı bir fark (p<0,05) gözlenmemiş; ancak 100, 150, 200 ve 250 mM tuzluluk uygulamalarında sırasıyla %79, %92, %94,7 ve %94,7 oranlarında azalma kaydedilmiştir. Sürgün yaş ağırlıkları tartılan Gözde çeşidinin kontrol ve uygulama grupları kıyaslandığında 50 mM NaCl'de istatistiksel fark (p<0,05) yokken, 150 mM NaCl uygulamasında %95 oranında azalma kaydedilmiştir. Gözde çeşidinde, yüksek tuz konsantrasyonlarının sürgün yaş ağırlığını belirgin şekilde azalttığı görülmüştür. Leoti çeşidinde ise sürgün yaş ağırlıklarında kontrole kıyasla en düşük azalma %15 oranında 50 mM tuzlulukta, en yüksek azalma ise %95 oranında 250mM NaCl konsantrasyonda kaydedilmiştir. Rox çeşidinde sürgün yaş ağırlığında en belirgin azalma, %90,3 oranında 250 mM tuzlulukta kaydedilirken, tuzluluğun en düşük olduğu 50 mM'da azalma oranı %16 olarak belirlenmiştir. Tuzluluğun artışı sorgum bitkisinde sürgün yaş ağırlıklarında azalmaya neden olmaktadır (Bavei vd., 2011; Punia vd., 2021).Sürgün kuru ağırlıkları üzerine tuz stresinin etkileri Şekil 3'te gösterilmiştir. Sorgum bitkisinin Akdarı çeşidinde kontrolle kıyaslanan uygulama gruplarının sürgün kuru ağırlıkları 50, 100, 150, 200 ve 250 mM NaCl uygulamaları ile sırasıyla %20, %55, %77,5, %82,5 ve %82,5 oranında azalmıştır. Aldarıda sürgün kuru ağırlıkları, kontrol grubuna kıyasla 50 mM tuzlulukta anlamlı bir fark (p<0,05) gözlemlenmemiş; ancak 200 ve 250 mM NaCl'de %87,5 oranında azalma kaydedilmiştir. Gözde çeşidinde en büyük azalma 250 mM tuzluluk uygulamasında %91,4 olarak kaydedilmiştir. Bir diğer sorgum çeşidi olan Leotide ise 50 mM NaCl kontrol grubuna kıyasla istatistiksel olarak anlamlı bir fark (p<0,05) oluşturmazken 250 mM NaCl'de %86,8 azalma olmuştur. Rox çeşidinde ise Leotidekine benzer şekilde kontrol grubu ile karşılaştırıldığında, 50 mM tuzluluk için istatistiksel bir fark (p<0,05) gözlemlenmemiştir. Diğer taraftan, 100 mM tuzlulukta %19,3 oranında bir azalma kaydedilirken, tuzluluk 250 mM'a ulaştığında azalma oranı %80,6 olarak belirlenmiştir. Sürgün kuru ağırlığındaki düşüşler, tuzluluk stresinin bitkilerde iletim sistemini kısıtlayarak büyümeyi engellemiş olabileceğini göstermektedir. Aydınşakir vd. (2012) sorgum

bitkisinin farklı çeşitlerinde yapmış oldukları çalışmada, artan tuzlulukla sürgün kuru ağırlığında azalmanın meydana geldiğini kaydederek çalışmamızla benzer bir sonuç ortaya koymuştur.

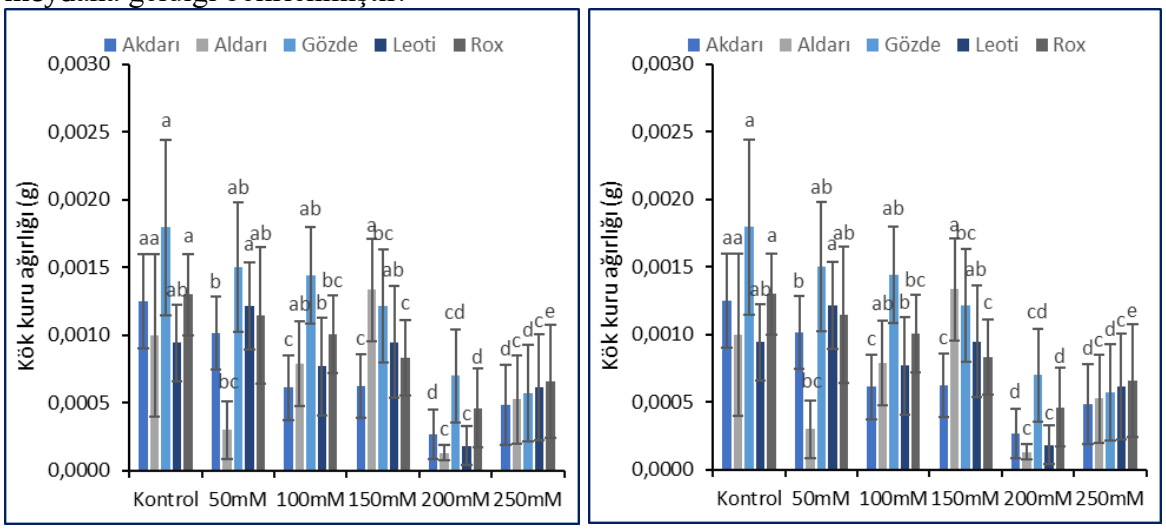


Şekil 3. Tuz stresine maruz bırakılan sorgum çeşitlerinde sürgün yaş ve kuru ağırlıklarında meydana gelen değişimler

Tuz stresinin sorgum çeşitlerinin kök yaş ağırlıklarında meydana getirdiği değişimler Şekil 4'te gösterilmiştir. Akdarı çeşidinin kök yaş ağırlıklarında kontrol ile 50, 100 ve 150 mM tuz konsantrasyonları kıyaslandığında anlamlı fark (p<0,05) görülmemiş; fakat 200 mM NaCl uygulaması ile % 57 ve 250 mM ile ise %55 azalma kaydedilmiştir. Aldarı çeşidinde kök yaş ağırlıklar kontrolle kıyaslanmış, en çok azalma 200 ve 250 mM NaCl uygulama gruplarında %77,7 olarak belirlenmiştir. Kök yaş ağırlıkları Gözde çeşidinde kontrolle kıyaslandığında, en yüksek artış %93,3 ile 250 mM tuzlulukta meydana gelirken 50 mM NaCl uygulamasında istatistiksel olarak anlamlı fark (p<0,05) meydana gelmemiştir. Leotide kök yaş ağırlık verileri incelendiğinde, kontrol grubuna kıyasla 50 mM NaCl uygulamasında %81,8 ve 150 mM NaCl'de %91 oranında artış kaydedilmiş; buna karşılık 100, 200 ve 250 mM NaCl uygulamalarında istatistiksel olarak anlamlı bir fark (p<0,05) belirlenmemiştir. Buradan yola çıkılarak, bitkinin farklı tuz seviyelerine verdiği tepkiler farklıdır. Rox çeşidinin kök yaş ağırlıklarında kontrol ve uygulama grupları kıyaslanmış, 50, 100 ve 150 mM NaCl uygulanan gruplarda istatistiksel anlamlı fark (p<0,05) bulunmamıştır. Ancak, 200 ve 250 mM tuzluluk seviyelerinde sırasıyla %37,2 ve %84,3'lük azalma gözlenmiştir.

Sorgum çeşitlerinde kök kuru ağırlığı üzerine tuz stresinin etkileri Şekil 4'te gösterilmiştir. Akdarı çeşidinin kök kuru ağırlığı verilerinde, kontrol grubuna kıyasla 50 mM NaCl'de %18,4 azalma görülürken 250 mM NaCl uygulamasında bu azalma %81,6'dır. Aldarı çeşidinin kök kuru ağırlıklarında 100 ve 150 mM tuzluluk uygulamalarında kontrolle arasında istatistiksel fark (p<0,05) bulunmazken, 50 mM NaCl'de %70, 200 ve 250 mM NaCl'de %90 oranında azalma kaydedilmiştir. Gözde çeşidinde en belirgin azalış %83,3 oranı ile 250 mM tuzlulukta kaydedilmiştir. Leotide kontrol ve uygulama grupları kıyaslanmış, 50, 100 ve 150 mM tuzlulukta anlamlı farklar (p<0,05) oluşmazken, 200 ve 250 mM tuz uygulamasında sırasıyla %79,7 ve %75,5

oranında azalma kaydedilmiştir. Rox çeşidi için kontrolle kıyaslanan uygulama gruplarında 50 mM NaCl uygulaması için anlamlı fark (p<0,05) oluşmazken, 250 mM'da %92,3 oranında bir azalma meydana gelmiştir. Bu bulgular, düşük ve orta düzey tuzlulukta kök kuru ağırlığının korunabildiğini, ancak yüksek tuzluluk seviyelerinde (200 ve 250 mM) kök gelişiminin baskılandığının göstergesi olabilir. Artan tuzluluk miktarı sorgum çeşitlerinin kök yaş ve kuru ağırlıklarında azalmalar meydana getirmiş ve kök gelişimini olumsuz etkilemiştir. Artan tuzluluk seviyesinde kinoa (Tan ve Akçay, 2019), soya (Kurt vd., 2023) ve mercimek (Tarhan ve Ceritoğlu, 2024) gibi farklı bitkilerde de çalışmamızla benzer şekilde kök kuru ağırlıklarında azalmaların meydana geldiği belirlenmiştir.

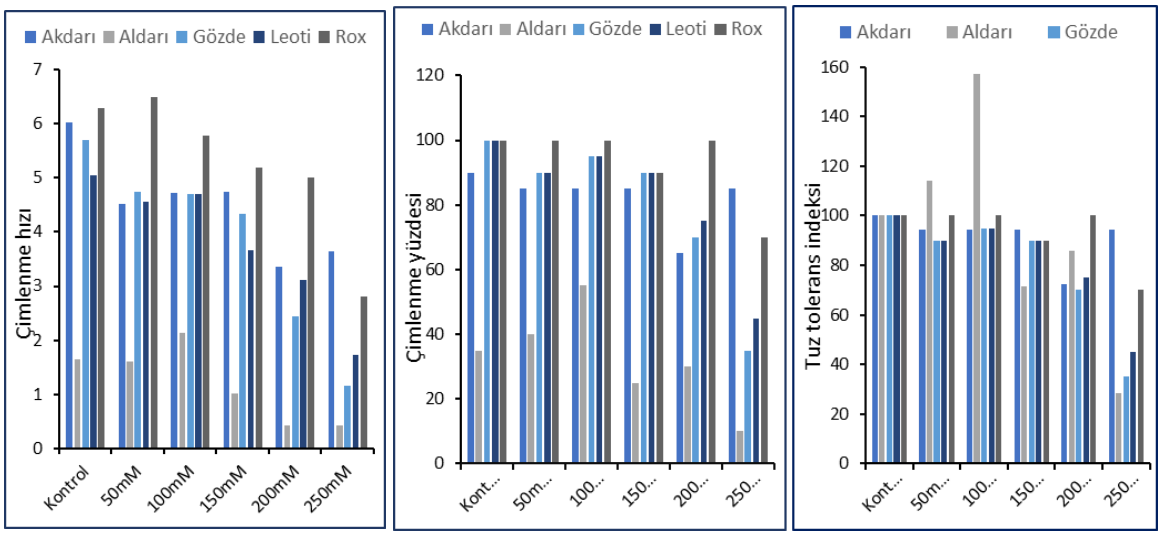


Şekil 4. Tuz stresine maruz bırakılan sorgum çeşitlerinde kök yaş ve kuru ağırlıklarında meydana gelen değişimler

Sorgum çeşitlerinin tuz stresi altındaki çimlenme hızı, çimlenme yüzdesi ve tuz tolerans indeksi değerleri Şekil 5'te sunulmuştur. Artan tuz konsantrasyonları genel olarak tüm çeşitlerde çimlenme hızı ve çimlenme yüzdesinde azalmaya neden olmuştur. Kontrol koşullarında çimlenme hızı en yüksek Rox (6,3) gelmekte olup onu Akdarı (6), Gözde (5,7), Leoti (5) ve Aldarı (1,6) takip etmektedir. 250 mM NaCl uygulamasında en düşük çimlenme hızı Aldarı (0,4), en yüksek Rox (3) çeşidinde gözlenmiştir. Tuzluluk koşullarında özellikle Rox ve Akdarı çeşitlerinin çimlenme hızları diğer çeşitlere kıyasla daha yüksektir; bu da söz konusu çeşitlerin tuz stresine karşı daha toleranslı olabileceğini göstermektedir. Aldarı her seviyede en düşük çimlenme hızına sahip olup tuza en duyarlı çeşit olarak öne çıkmaktadır. Bu bulgular, literatürde yer alan ve tuz stresinin bitkisel gelişim üzerinde baskılayıcı etkiler yarattığını belirten çalışmalarla uyum göstermektedir (Parlak ve Özaslan Parlak, 2006; Bavei vd., 2011; Kaur vd., 2023).

Kontrol koşullarında çimlenme yüzdesi Gözde, Leoti ve Rox çeşitlerinde %100, Akdarıda %90 civarındayken, Aldarıda %35'tir (Şekil 5). 50 ve 100 mM NaCl konsantrasyonlarında Rox çeşidi çimlenme yüzdesini %100'e yakın korurken, Leoti, Gözde ve Akdarı çeşitlerinde çimlenme %85 ile %95 arasında değişmiştir. Buna karşın Aldarı çeşidinde çimlenme yüzdesi sırasıyla %35 ve %55 düzeylerinde kalmıştır. 200 ve 250 mM NaCl'de, özellikle Aldarı ve Gözde çeşitlerinde çimlenme yüzdesi önemli ölçüde azalmıştır. Rox ise 200 mM NaCl uygulamasında %100 çimlenme kaydederek yüksek tolerans göstermiş ve bu çimlenme yüzdesi 250 mM tuzlulukta dahi %70 seviyelerinde kalmıştır.

Tuz tolerans indeksine bakıldığında kontrol grubu tüm çeşitlerde %100 değerlendirilmiştir (Şekil 5). 50 mM NaCl'de, Aldarı, %114,2 ile en yüksek tuz tolerans indeksine sahipken, Gözde ve Leoti %90 civarına düşmüştür. 100 mM NaCl uygulamasında, Aldarı çeşidinde tuz tolerans indeksi dikkat çekici şekilde %157'ye çıkarak diğer çeşitlerden farklı sonuç sergilemiştir. Aynı konsantrasyonda Rox çeşidinde tuz tolerans indeksi %100 civarında iken diğer çeşitler %95 civarındadır. 150 mM NaCl uygulamasında, çeşitlerin çoğu %90–95 arasında tuz tolerans indeksine sahipken Aldarıda, tuz tolerans indeks verisi %71,4'e kadar gerilemiştir. 200 mM NaCl uygulamasında, Rox tuz tolerans indeksini %100'e yakın korurken, diğer çeşitler %70 ile 85 aralığında tutmuştur. 250 mM tuzlulukta ise Rox çeşidi %70 ile en yüksek tuz tolerans indeksine sahipken, Aldarı %30'un altına düşmüştür. Leoti ve Gözdede bu indeks %40-50 civarında gözlenmiştir. Bu veriler, çeşitlerin tuz stresine verdiği tepkilerin uygulama dozu ile birlikte değiştiğini ve Rox'un yüksek tuz tolerans indeksine sahip olması ile öne çıktığını göstermektedir.



Şekil 5. Tuz stresine maruz bırakılan sorgum çeşitlerinde çimlenme hızı, çimlenme yüzdesi ve tuz tolerans indeksinde meydana gelen değişimler

3. SONUÇ

Sorgum, insan beslenmesi, hayvan yemi, biyoyakıt üretimi ve endüstriyel kullanım gibi pek çok alanda değerlendirilebilmesi sayesinde tarım ve ekonomi açısından önemli bir bitkidir. Sorgum tohumlarının tuzluluk koşulları altında çimlenme performansının incelenerek stres toleransının ortaya konulmuş ve tuzlu arazilerde sorgum tarımının sürdürülebilir olması adına veriler kaydedilmiştir. Sorgum bitkisinin Akdarı, Aldarı, Leoti, Gözde ve Rox çeşitlerine farklı konsantrasyonlarda tuzluluk uygulanmış, optimum çimlenme şartları ve tohumların tuzluluğa toleransları belirlenmiştir. Tuz konsantrasyonunun artması tüm sorgum çeşitlerinde sürgün ve kök uzunluğunda, sürgün ve kök yaş ve kuru ağırlıklarında azalmalara neden olmuştur. Özellikle 200 ve 250 mM NaCl konsantrasyonda tuzluluk çeşit bazında sürgün uzamasını engellemiştir. Sürgün uzamasını durduran çeşitlerde kök sistemi daha iyi korunmuş ve kök uzunluğunda artış gözlenmiştir. Leoti çeşidi sürgün ve kök uzunluğunu artan tuz konsantrasyonlarında en iyi koruyabilen çeşit olurken Aldarı çeşidi daha hassastır. Sorgum çeşitlerinin sürgün yaş ve kuru ağırlıkları 50 mM tuzlulukta önemli değişimler göstermese de 100 mM NaCl ile farklı tepkiler kaydedilmiştir. Özellikle Aldarı çeşidinde ağırlıklarda azalmalar gözlenirken Leoti ve Rox çeşitleri sürgün yaş ve kuru ağırlıklarını önemli noktada muhafaza etmişlerdir. Diğer taraftan, Gözde çeşidi

kök yaş ve kuru ağırlığındaki değişim ile tuza en dayanıklı çeşit olarak öne çıkmaktadır. Artan tuz konsantrasyonları genel olarak tüm çeşitlerde çimlenme hızı ve çimlenme yüzdesinde azalmaya neden olmuştur. Özellikle Aldarı çeşidinde tuz tolerans indeksi yüksek konsantrasyonlarda belirgin şekilde düşerken, Gözde, Leoti ve Rox çeşitlerinde bu düşüş daha sınırlı kalmıştır. Bu durum, Gözde, Leoti ve Rox çeşitlerinin tuz stresine karşı daha toleranslı olabileceğinin göstergesi olabilir. Tüm parametreler göz önünde bulundurulduğunda, artan tuz seviyeleri çeşit ve ölçüm açısından kısıtlayıcı etki göstermektedir. Ancak Leoti, Rox ve Akdarı çeşitleri belirli düzeylerdeki tuzluluk koşullarında büyüme özelliklerini kısmen koruyabilirken, Aldarı çeşidi tüm parametrelerde oldukça hassas bir görüntü sergilemiştir. Elde edilen bulgular, tuzluluk sorunu yaşayan arazilerde, tuzluluk stresine karşı dayanıklı sorgum çeşitlerinin seçilmesine olanak tanıyarak, tarımda verim kayıplarının azaltılması ve marjinal alanların tarıma kazandırılması açısından önemli veriler sunmaktadır.

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METAVERSE MARKETING: NEW STRATEGIES FOR CUSTOMER ENGAGEMENT

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ABSTRACT
This research explores how major brands are joining forces for brand exposure and customer interaction in the metaverse with specific reference to Nike, Gucci, Samsung, Vans and Coca-Cola. The paper presents campaigns and marketing strategies that demonstrate how virtual environments redefine the consumption experience with the brands. Gamification, digital merchandise (NFTs), and immersive storytelling are the tools that brands are employing for creating custom, interactive experiences based on the interests of the millennial or Z-Generation audiences. Examples such as virtual events, community development, and hybrid marketing approaches highlight to the reader the function of the metaverse as a tool for experimentation, loyalty building, and emotional branding. The metaverse future poses both exciting promises and daunting challenges for marketers in keeping abreast socially relevant and ethically responsible in a digital-first culture. It describes how the metaverse is reshaping the very foundations of marketing in the present day.
Keywords: Metaverse Marketing; Virtual Consumer Engagement; Brand Storytelling; Gamification; Digital Merchandise (NFTs)

INTRODUCTION

A metaverse is a collective, virtual shared space, created by perceptions of virtually-enhanced physical reality-digital reality combo (Cheng, 2023; Dolata and Schwabe, 2023). In short, with the imminent advancements in technologies such as VR, AR, AI, and Blockchain, the metaverse is no longer some distant point in time; it is today an inhabitable and evolving area with real-world applications (Wang et al., 2022). From the marketer's perspective, the metaverse is a unique opportunity whereby audiences are engaged in a new and innovative manner with high interactivity.

With real-time, three-dimensional interactions between consumers and brands, the metaverse is, therefore, a new, innovative paradigm that separates itself from existing digital platforms (Park and Kim, 2022; Ritterbusch and Teichmann, 2023). It empowers the audience as an active participant rather than a passive observer, allowing brands to tell stories, create experiences based on individual preferences, and forge deeper relationships. Within the metaverse, consumers are not just spectators but co-creators, collaborators, and community members.

This becomes highly significant in an era of rising digital fatigue and saturation advertising. The metaverse, in contrast, becomes a remedy for less intrusive techniques to capture user attention through captivating, gamified, and immersive experiences (Jo et al., 2025; Yadav et al., 2024). Those early initiators of this transition will have a strong competitive advantage in reaching and maintaining a new generation of consumers, especially that Gen Z and Millennials who are digital natives in every sense.

The paper aims to explain how brands enter and evolve marketing strategies in the metaverse. This study conducts a critique of campaigns by Nike, Gucci, Samsung, Vans, and Coca-Cola and analyses a temporal reading to identify good practices and trends that will inform future marketing activity into a virtual space.

RESEARCH AND FINDINGS

1. Nike's NIKELAND on Roblox: Nike has established NIKELAND, which is branded as such on Roblox, where users can engage in games, customize avatars with Nike gear, and participate in sports-related activities (Temperino, 2023). It builds brand loyalty by encouraging interactive experiences and user-generated content that effectively make advocates of the brand out of players. Similarly, Nike integrates physical challenges into its platform so as to encourage movement and associate the brand with fitness culture (Pratas et al., 2025). This hybrid model also allows Nike to do product testing and seek consumer opinions ahead of real-world distribution. NIKELAND not only allows for competitions but also tie-ins with community events, so that the experience is ever-fresh and dynamic.

2. Gucci Garden Experience: Gucci launched a virtual fashion exhibition called "Gucci Garden" on Roblox, which allowed users to wander through themed rooms inspired by Gucci's collections and buy limited-edition digital merchandise (Sepe and Anzivino, 2020). The virtual purse sold for well over its analog counterpart, which may be seen as an indication of how value systems are changing in digital environments, reinforcing the notion that consumers are willing to pay for virtual luxury. Gucci Gardens also acted as a platform for storytelling and user engagement with the brand's artistic interpretation of its heritage (Jiang et al., 2023). Gucci's campaign proved that high fashion could have meaningful translation rights in virtual reality, thus furthering its prestige amongst younger audiences. The campaign also began a new territory for luxury-brand positioning, thus placing Gucci at the forefront of digital haute couture.

3. Samsung's 837X in Decentraland: Samsung has created a virtual copy of its flagship store, 837X, within the metaverse of Decentraland. This venue hosted activities, NFT giveaways, and

even live performances. By fusing the brand's narrative with gamification, Samsung attracted a better audience toward tech-savvy consumers and hence improved their awareness of digital initiatives. It also highlighted Samsung as a forward-looking tech firm that accepts the culture of Web3 and sustainability (Chung, 2022). Thus, the virtual experience was entirely within the goals of their environment. Also, as clarified by Samsung's activities in Decentraland, this is an important aspect of leading the brand into metaverse innovation. In addition, using rewards backed by blockchain for engagement, Samsung encountered previously unbidden horizons in digital loyalty programs and created decentralized brand ecosystems.

4. Vans World and Virtual Skate Parks: Vans has now made their move, having launched the Vans world on Roblox where users can practice tricks and even skate parks and customize their virtual shoes (Lamba and Malik, 2022). The implementation has now helped the company create and legitimize its identity with Gen Z users while creating a larger virtual community for their skateboarding culture. It also opens up the possibility of future experiential product placements and direct virtual-to-physical future sales opportunities. Vans used Roblox's creative tools for user input on content while positioning itself within that counter and youth audience. The model allows co-creation, with players able to create their own personal skate parks and gear, further deepening brand interaction and affinity.

5. Coca-Cola's Friendship Day NFT Campaign: On the occasion of International Friendship Day, Coca-Cola presented a special collection of branded NFTs that included digital wearables for avatars and exclusive virtual experiences (Le et al., 2025). The campaign merged nostalgic branding with digital engagement for the future, appealing to NFT developers and to Coca-Cola's loyal consumers. It showcased Coca-Cola's adaptability to the modern digital culture while strengthening the iconic brand image (Maheshwari et al., 2025). The metaverse, for Coca-Cola, was an avenue for visibility as well as an emotional branding tool-a reflection of friendship and togetherness. The program demonstrated how emotional storytelling can be dramatically transferred into the metaverse through limited-edition digital art and social experiences.

Key Strategies Identified:

- **Gamification:** Brands are integrating gaming mechanics to create engaging and fun experiences.
- **Digital Merchandise and NFTs:** Creating exclusive virtual items for the limited runs is a way to generate exclusiveness and increase demand.
- **Virtual Events:** Live performances, product launches, and exhibitions draw large crowds and offer memorable interactions.
- **Community Building:** Encouraging participation by the user, sharing as such and virtual co-creation increase people's loyalty.
- **Storytelling and Immersion:** It is through the virtual worlds themselves that brands tell stories which deepen emotional connection with the stories of emerging consumers.
- **Personalization:** Personalized avatar, experience, and shopping options make it possible for retailers to cater to such commitment.
- **Hybrid Marketing Models:** Linking virtual experiences to real-world products and promotions blurs the line between physical and digital engagement.

CONCLUSION

Brands interested in connecting with digitally native audiences find metaverse marketing to be a disruptive instrument in contemporary times. Companies can create customized and memorable experiences for audiences beyond traditional marketing avenues using immersive environments and interactive content. The virtual environment works as an entertainment medium

and also as a tool for educating customers, letting them try their products, and, finally, about brand storytelling.

However, along with technological evolution comes the need for brands to prioritize innovation while considering ethical dilemma: data privacy, inclusivity, and mental wellness in this digital space. Finally, the hallmark of a successful metaverse marketing initiative is a brand that is culturally relevant and technologically nimble while remaining focused on the consumer.

The successful adventures of Nike, Gucci, Samsung, Vans, and Coca-Cola tell us that metaverse marketing is not a fad, but almost revolutionary in its potential for transforming the actual landscape for customer engagement. Possible further study could focus on the impact of virtual branding on consumer behavior over the long term and how smaller firms could utilize metaverse marketing while not breaking the bank.

In conclusion, the metaverse is on the edge of initiating a new marketing revolution. This is an odyssey of rethinking how marketers deliver value, establish emotional bonds, and nurture consumer trust in decentralized and digital-first realms. The growing accessibility of the metaverse means that, as it becomes more developed, marketers would need to know and be able to harness it to stay relevant and to achieve strategic success in the digitally immersive future.

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YEŞİL MERCİMEK ÇEŞİTLERİNDE VERİM ÖĞELERİ ARASINDAKİ İLİŞKİLERİN BELİRLENMESİ ÜZERİNE BİR ARAŞTIRMA

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ÖZET
Bazı yeşil mercimek çeşitlerinin Sivas ekolojik koşullarında verime etki eden özellikler arasındaki ilişki dereceleri ile olumsuz/olumlu yönlerinin ortaya konulması amacıyla yürütülen bu çalışma 2024 yılında mercimek yetiştirme sezonunda gerçekleştirilmiştir. Çalışmada 10 adet mercimek çeşidi (Ankara Yeşili, Bozok, Ceren, Çiftçi, Gümrah, Kafkas, Karagül, Meyveci 2001, Pul 11 ve Sultan) yer almıştır. Gerek korelasyon gerekse path analizinin yapılması amacıyla ele alınan agronomik özellikler olarak bitki boyu, ilk bakla yüksekliği, biyolojik verim, ana dal sayısı, bitkide bakla sayısı, bitkide tane sayısı, bin tane ağırlığı, hasat indeksi, bitkide tane verimi ve dekara tane verimi gibi özellikler araştırılmıştır. Yeşil mercimek çeşitleri üzerinden yürütülen çalışmada ortaya konulan sonuçlara göre dekara tane verimi ile bitki boyu ve ana dal sayısı arasında pozitif ve çok önemli ilişkiler görülmüştür. Ayrıca bitkide tane verimi ile bitki boyu, ilk bakla yüksekliği, biyolojik verim, ana dal sayısı, bitkide bakla sayısı, bitkide tane sayısı ve hasat indeksi arasında da çok önemli ve pozitif ilişkiler tespit edilmiştir. Sonuç olarak yeşil mercimekte ıslah araştırmalarında bitkide bakla ve bitkide tane sayıları, bin tane ağırlığı, bitkide tane verimi ve dekara tane veriminin seleksiyon kriterleri olarak dikkate alınmalarının önemli olduğu sonucuna varılmıştır.

Anahtar Kelimeler: Sivas, Yeşil mercimek, Çeşit, Korelasyon, Path analizi

1. GİRİŞ

Yaklaşık günümüzden 9-10 bin yıl önce Ortadoğu'da ilk kez kültüre alınan ve bu coğrafi bölgeden Akdeniz Bölgesi ile Asya ve Avrupa kıtalarına kadar yayılan Mercimek (*Lens culinaris* Medik.), ülkemizde ise Güneydoğu Anadolu Bölgesi'ni içine alan "verimli hilal" denilen Mezopotamya Bölgesinden buğday ve arpadan hemen sonra nohut ile beraber kültüre alınmaya başlamış ve buradan da tüm dünyaya yayılmıştır (Cubero 1981). Yüksek düzeyde besleyici özelliklerine sahip mercimek, aynı zamanda yüksek oranda protein, karbonhidrat, vitamin ile mineral madde içeriklerine sahip olup sadece taneleri için yetiştiriciliği yapılmaktadır. Yetiştiriciliği yapılan çeşide ve ekolojik faktörlere göre değişmekle beraber mercimek, tanesinde yaklaşık %25-30 düzeyinde protein bulundurmaktadır (Eser 1981). Dünya coğrafyası üzerinde az gelişmiş ve gelişmeye yeni başlayan ülkelerde insan beslenmedeki protein açığının belli ölçüde kapatılmasında önemli bir kaynak oluşturan mercimek aynı zamanda tahıl sap ve samanının iki katı (%4-5) protein içeren sap ve samanı ile de hayvan beslemesine de önemli katkılar yapmaktadır (Şehirali, 1988). Bir baklagil bitkisi olan mercimeğin köklerinde yer alan nodüller ile toprak içeriğinde bağımsız yaşayan "*Rhizobium leguminosarum*" bakteri türleri ortak yaşama girerek havanın serbest azotunu organik azot formunda toprağa bağlayarak toprağı da zenginleştirebilmektedir. Mercimek ekili bulunduğu alanda simbiyotik yolla toprağa 8,4 kg/da azot bağlayabilmektedir (Şehirali, 1988). Yüksek protein içeriğine sahip olmaları, toprağı organik madde kazandırarak zenginleştirmeleri, kazık kökleri sayesinde toprağı havalandırmaları, kuru tarım alanlarında tahıllar ile ekim nöbetine girebilmeleri ve en önemlisi kuru tarım bölgelerinde çiftçi için iyi bir gelir kaynağı olmaları nedeniyle mercimek, günümüzde münavebe bitkisi olarak önerilecek en iyi baklagil bitkilerinden birisi olarak kabul edilmektedir.

Türkiye, dünyadaki önemli mercimek üretici ülkelerden birisi olup ekim alanı ve üretim bakımından Hindistan, Kanada ve Avustralya'nın ardından dördüncü sırayı almaktadır (FAO, 2023). Türkiye mercimek ticareti bakımından da önemli ülkeler arasında olup ülkemizde 2023 yılı itibariyle 569.265 ton mercimek ihracatına karşılık 557.733 dolarlık bir gelir elde edilmiştir. Buna karşın 613.467 dolar tutarında 860.271 tonluk mercimek ithalatı gerçekleşmiştir.

Mercimek, kıyı şeritleri hariç ülkemizin tüm coğrafi bölgelerinde yetiştirilmekle beraber kışı sert geçen İç Anadolu ve Doğu Anadolu Bölgesi ile Geçit Bölgelerinde erken ilkbaharda, Doğu Akdeniz Bölgesi'nde ise kış aylarında yetiştiriciliği yapılabilmektedir. İlkbahar ekimlerinde bitkiler belli bir dönemden sonra yüksek sıcaklık stresine girdikleri takdirde tane veriminde ciddi kayıplar yaşanabilmektedir. Düşük sıcaklıklar ile değişebilen sıcaklıklara karşı dayanımı bakımından yemeklik tane baklagiller içinde ilk sırayı alan mercimek, kışlık tahıl-nadas ekim nöbetinin uygulandığı özellikle kurak bölgelerimizden olan İç Anadolu Bölgesi'nde münavebeye girerek tane verimini artırmada ve nadas alanlarımızı daraltmada önemli bir üstünlüğe sahiptir.

Gerek fenolojik, gerek morfolojik gerekse agronomik özelliklerin karşılıklı interaksiyonları, bitkilerin verim değerini ortaya koyabilmektedir. Islah süreci bakımından verim öğelerinin kendileri ve birbirleri üzerindeki etki şiddetlerinin belirlenmesi son derece önemli olup verim özelliklerinin kendi aralarındaki ilişkilerin yönü ve şiddetini ortaya koymada korelasyon katsayısı (R) detaylı bilgi verememektedir. Çünkü verime etki eden birçok özellik, verim üzerine indirekt etki yapabilmektedir. Bir Amerikalı bilim adamı olan Sewall Wright tarafından geliştirilen path katsayısı modeli, gerek direkt gerekse indirekt olarak verimi etkileyen birçok özelliğin belirlenmesinde yardımcı olmuştur. Adı geçen bu model, bir değişkenin başka bir değişkene olan etkisini direkt ve indirekt olarak ortaya koyabilmektedir. Path katsayısı analizi bir değişkenin diğer

bir değişkene olan doğrudan ve dolaylı etkisini ortaya çıkaran bir analiz metodudur. Diyarbakır'da 48 mercimek tohum örneğinden tesadüfen seçilen 765 saf mercimek hattında 1995 yılında özellikler arası ilişkiler belirlenmesi üzerine yürütülen araştırmada incelenen tüm özellikler bakımından büyük değişkenlikler görüldüğü bildirilmiş olup tane veriminin çiçeklenme ve vejetasyon süresi ile olumlu ilişki gösterdiği, bunun yanında çiçeklenme ile vejetasyon süresi arasında pozitif ve istatistiki olarak önemli ilişkiler bulunduğu Şakar ve Biçer (2001) tarafından rapor edilmiştir. Özdemir ve Karadavut (2003), verim ve verime etki eden parametreleri korelasyon ve path analizleri ile belirlemenin daha başarılı olduğunu ifade etmişlerdir. Kumar ve ark. (2004), 1996-1997 yılları arasında Hindistan'daki farklı ikim ve toprak koşullarında özellikler arası ilişkilerin belirlenmesi üzerine yürüttükleri araştırmalarında çiçeklenme gün sayısının tane verimi üzerinde önemli olduğunu bildirmişlerdir. Aydoğan ve ark. (2006), verim ile kış zararı okuma değerleri arasında önemli ve olumsuz (-0.845**), çiçeklenme gün sayısı ile bitki boyu arasında önemli ve olumlu (0.756**), çiçeklenme gün sayısı ile kış zararı arasında önemli ve olumlu (0.625*), 1000 tane ağırlığı ile kış zararı arasında önemli ve olumsuz (-0.790**), 1000 tane ağırlığı ve verim arasında önemli ve olumlu (0.860**) ilişkiler elde etmişlerdir. Islah üzerine yürütülecek çalışmalarda yetiştirilecek bölgelere adaptasyon çalışmaları yapılırken özellikle verim öğeleri arasındaki ilişkiler ile bu özelliklerin verim ya da dekara tane verimi üzerinde doğrudan ve dolaylı etkilerinin bilinmesi ıslah çalışmaları açısından önemlidir (Younis ve ark., 2008). Karadavut ve Sözen (2019), Kırşehir ekolojik koşullarında 31 köy çeşidi ile özellikler arası ilişkiler belirlenmesi üzerine yürüttükleri mercimek denemesinde bitki bakla sayısı ve bitkide tane sayısı özelliklerinin kalıtım derecesinin çok yüksek olduğunu ve genotip x yıl interaksiyonlarına göre değiştiğini ve seleksiyonda bu iki özelliğin önemli olduğunu açıklamışlardır. Dekara tane veriminin bin tane ağırlığı hariç tüm parametrelerle olumlu ve önemli ilişkiler sergiledikleri Sözen ve Yağmur (2020) tarafından ortaya konulmuştur. Adak (2021), bitkide bakla sayısı ve tane sayısının genetik yapı, ekim sıklığı ve yetiştirme tekniği paketinde yer alan işlemlere göre değişebildiğini, bu iki özelliğin de tohum verimini belirleyen en önemli verim öğeleri arasında olabileceğini vurgulamıştır.

Sivas ekolojik koşullarında bazı yeşil mercimek çeşitlerinde gerek verim gerekse verime etki eden birçok parametre arasındaki ilişkilerin yönü ve şiddeti ile bu parametrelerin direkt ve indirekt etkilerinin ortaya konulması, bu araştırmanın amacını oluşturmaktadır.

2. MATERYAL ve METOT

2.1. Materyal

Bu araştırmanın tarla çalışmaları Sivas Bilim ve Teknoloji Üniversitesi'nin Tarımsal AR-GE Merkezinde yer alan deneme arazisinde 2024 yılı mercimek vejetasyon döneminde yürütülmüştür. Araştırmanın yürütüldüğü lokasyon deniz seviyesinden yaklaşık 1285 m yükseklikte, N39,720656 - E36,917248 konumunda bulunmaktadır (Şekil 1).

Şekil 1. Araştırmanın yürütüldüğü deneme arazisi

Araştırmada, ülkemizde Tarımsal Araştırmalar ve Politikalar Genel Müdürlüğüne bağlı Tarımsal Araştırma Enstitüleri tarafından tescil ettirilmiş olan 10 adet yeşil mercimek çeşidi kullanılmıştır (Tablo 1).

Tablo 1. Çalışmada kullanılan çeşitler ile tescil ettiren kuruluşlar

Mercimek Çeşitleri	Tescil Ettiren Kuruluş
Sultan	Geçit Kuşağı Tarımsal Araştırma Enstitüsü Müdürlüğü / Eskişehir
Ankara Yeşili	Tarla Bitkileri Merkez Araştırma Enstitüsü Müdürlüğü / Ankara
Kafkas	
Gümrah	
Karagül	
Meyveci 2001	
Bozok	
Çiftçi	
Ceren	
Pul 11	

2.2. Araştırma Yerinin İklim Özellikleri

Sivas ilinin mercimek yetiştirme dönemine ait uzun yıllar ortalaması (1980-2023) ile araştırmanın yürütüldüğü 2024 yılının meteorolojik değerleri incelendiğinde uzun yıllar ortalaması ile 2024 yılına ait aylık sıcaklık ortalamaları ve aylık toplam yağış değerleri arasında Nisan ayı hariç büyük bir farkın olmadığı belirlenmiştir. Bununla birlikte 2024 yılı aylık ortalama nisbi nem değerlerinin de uzun yıllar ortalamasıyla paralellik gösterdiği Tablo 2'de görülmektedir.

Tablo 2. Sivas ilinin 2024 yılı ile uzun yıllara ait iklim verileri

Aylar	Ortalama Sıcaklık (^{0}C)		Toplam Yağış (mm)		Ortalama Nisbi Nem (%)	
	2024	Uzun Yıllar	2024	Uzun Yıllar	2024	Uzun Yıllar
Nisan	13.9	8.9	11.2	56.9	52.85	44.8
Mayıs	13.1	13.5	60.0	60.9	63.71	61.5
Haziran	20.9	17.0	11.6	34.5	59.45	58.0
Temmuz	22.0	20.0	37.0	9.2	53.25	49.1
Ağustos	22.0	20.2	10.2	6.8	47.43	45.9
Toplam	-	-	130.0	168.3	-	-

2.3. Toprak Özellikleri

Çalışmanın yürütüldüğü deneme arazisinin toprak öğeleri incelendiğinde deneme parselinin toprağının alkali seviyesinin hafif (7.28), organik madde içeriğinin orta (%1.7), alınabilir fosfor (3.40) ve potasyum düzeyleri (93.59) bakımından orta, tuz seviyesinin tuzlu (%0.33) ve kireç içeriğinin ise kireçli (19.6) olduğu ortaya konulmuştur (Tablo 3).

Tablo 3. Deneme yeri toprağının fiziksel ve kimyasal özellikleri

Derinlik	0-30 cm
pH	7.28
Toplam Tuz (%)	0.33
Kireç (% CaCO3)	19.6
Organik Madde (%)	1.7
Fosfor (P2O5 kg/da)	3.40
Potasyum (K2O)	93.59

2.4. Yöntem

Yürütülen çalışmada deneme arazisinin ön bitkisi buğday olup buğday hasadı sonrasında deneme yeri erken ilkbaharda pullukla derin bir şekilde sürülmüştür. Ekim işleminden hemen önce denemenin yürütüleceği araziye önce kazayağı sokularak yabancı otlardan temizlendirilmiş ardından rotovatör ile deneme alanı ekime hazır hale getirilmiştir. Araştırma, Tesadüf Blokları Deneme Deseninde kurulmuş olup denemede 10 adet yeşil mercimek çeşidi her blok içerisinde rastgele dağıtılmıştır. Araştırmanın ekimleri 25 Nisan 2024 tarihinde gerçekleştirilmiş olup ekimler 20 cm sıra aralığında 2-3 cm sıra üzerinde, her bir sıraya 150-200 adet tohum düşecek şekilde markörle açılan sıralara 3 cm derinliğe elle yapılmıştır. Her parsel 4 sıradan oluşmuştur. Yabancı otlarla mücadele etmek üzere ekimlerle beraber ekim sonrası ve çıkış öncesi yabancı ot ilacı uygulanmış ve tüm vejetasyon süresince 2 sefer çapa yapılmıştır. Her parsele eşit olarak dekara 15 kg DAP (2,7 kg N/da ve 6,9 kg P_2O_5/da) gübresi ekimle birlikte toprağa verilmiştir. Araştırmanın yürütüldüğü deneme alanındaki çeşitlerin hasadı, hasat olgunluğuna ulaştıkları dönem aralığı olan 25 Temmuz-10 Ağustos 2024 tarihleri arasında el ile yapılmıştır. Parseli oluşturan 4 sıradan her iki yandaki birer sıra ve sıra başlarından 50 cm'nin içerisinde bulunan bitkiler kenar tesiri olarak gözlem dışı bırakılarak bütün işlemler 4 m x 0.4 m = 1.6 m^2'lik alanlar üzerinden yapılmıştır. Her bir parselden hasat edilen bitkiler ayrı ayrı çuvallara konulup etiketlenerek hasat-harman sonrası gerekli ölçümler ve analizler yapılmak üzere Sivas Bilim ve Teknoloji Üniversitesi Tarım Bilimleri ve Teknoloji Fakültesi Tarla Bitkileri Bölümü'nün harman laboratuvarına getirilmiştir.

2.5. Verim ve Bazı Bitkisel Özelliklerin Belirlenmesi

Her parselden rastgele seçilen 10'ar bitkide bitki boyu, ilk bakla yüksekliği, biyolojik verim, ana dal sayısı, bitkide bakla sayısı, bitkide tane sayısı, bin tane ağırlığı, hasat indeksi, bitkide tane verimi ve dekara tane verimi değerleri saptanmış ve bunların ortalamaları alınarak bitki başına ortalama değerler hesaplanmıştır.

2.6. Verilerin Değerlendirilmesi

Araştırma sonucunda elde edilen verilerden değişkenlerin aralarındaki doğrusal ilişkiler için korelasyon analizi ve dolaylı etkiler için ise path analizi yapılmış olup bu işlemler JUMP.13 istatistik paket programında gerçekleştirilmiştir.

3. ELDE EDİLEN BULGULAR ve TARTIŞMA

3.1. Korelasyon Analizi

Sivas ekolojik koşulları altında yürütülen araştırmada 10 adet yeşil mercimek çeşidinde ele alınan ve incelenen 10 adet agronomik özellik arasındaki korelasyon katsayıları belirlenerek özellikler arası ilişkilerin yönü ve önemlilik seviyeleri Tablo 4'de verilmiştir.

Tablo incelendiğinde bitki boyu ile ilk bakla yüksekliği (r= 557**), ana dal sayısı (r= 0.521**), 1000 tane ağırlığı (r= 0.562**), hasat indeksi (r= 0.568**), bitkide tane verimi (r= 0.410**) ve dekara tane verimi (r= 0.527**) arasında çok önemli ve olumlu; biyolojik verim (r= 0.271*), bitkide bakla sayısı (r= 0.311*) ve bitkide tane sayısı (r= 0.286*) ile önemli ve olumlu ilişkiler belirlenmiştir. 2002-2004 yılları arasında Orta Anadolu ve Geçit Bölgelerine adapte olabilen verimli, makineli hasada uygun ve kaliteli kışlık mercimek çeşitleri geliştirmek amacıyla yürütülen çalışmada verim ile bitki boyu arasında önemli ve olumlu (0.756 **); 1000 tane ağırlığı ve verim arasında önemli ve olumlu (0.860 **) ilişkilerin görüldüğü Aydoğan ve ark. (2006) tarafından ifade edilmiştir.

İlk bakla yüksekliği ile 1000 tane ağırlığı (r= 0.519**) ve bitkide tane verimi (r= 0.411**) arasında çok önemli ve olumlu; biyolojik verim (r= 0.320*), ana dal sayısı (r= 0.269*), bitkide bakla sayısı (r= 0.391*), bitkide tane sayısı (r= 0.330*) ve hasat indeksi (r= 0.388*) ile önemli ve olumlu ilişkiler saptanırken dekara tane verimi (r= -0.222*) ile ise önemli fakat olumsuz ilişkiler görülmüştür. Aydoğan ve ark. (2003) tarafından yeşil mercimek yerli popülasyonlarını karakterize etmek ve mercimek ıslahında seleksiyon kriterleri olarak alınacak karakterleri belirlemek amacıyla Orta Anadolu ve Kuzey Geçit Bölgelerindeki 12 ilden (Yozgat, Çorum, Çankırı, Kırşehir, Kırıkkale, Sivas, Tokat, Amasya, Nevşehir, Kayseri, Niğde ve Ankara) toplanan 334 yeşil mercimek çiftçi popülasyonunu 25 özellik açısından karakterize edilmiş olup gerçekleştirilen gözlem ve ölçmeler sonucunda incelenen karakterler arasında en yüksek korelasyon değerlerinin bitkide bakla sayısı ile bitkide tane sayısı (0.738**), biyolojik verim ve tane verimi (0.593**), biyolojik verim ve bitki boyu (0.387**) ve ilk bakla yüksekliği ile bitki boyu (0.291**) arasında bulunduğu görülmüştür. Biyolojik verim ile ana dal sayısı (r= 0.431**), bitkide bakla sayısı (r= 0.714**), bitkide tane sayısı (r= 0.982**) ve bitkide tane verimi (r= 0.955**) arasında çok önemli ve olumlu; dekara tane verimi (r= 0.263*) ile önemli ve olumlu; hasat indeksi (r= 0.246) ile önemsiz ve olumlu ilişkiler görülürken buna karşın 1000 tane ağırlığı (r= -0.225) ile ise önemsiz fakat olumsuz ilişkiler tespit edilmiştir. Van koşullarında ele alınan hat/çeşitler bakımından incelenen özellikler arasında ilişkilerin derecesinin ve yönünün belirlendiği çalışmada tane verimi ile bitki boyu (r= 0.338**), bitkide bakla sayısı (r= 0.419**), bitkide tane sayısı (r= 0.239*) ve bitkide tane verimi (r= 0.301 *) arasında olumlu ve önemli ilişkilerin tespit edildiği Bildirici ve Çiftçi (2001) tarafından rapor edilmiştir. Ana dal sayısı ile bitkide bakla sayısı (r= 0.706**), bitkide tane verimi (r= 0.447**) ve dekara tane verimi (r= 0.645**) arasında çok önemli ve olumlu; bitkide tane sayısı (r= 0.388*) ile önemli ve olumlu; 1000 tane ağırlığı (r= 0.107) ve hasat indeksi (r= 0.194) ile ise önemsiz ve olumlu ilişkiler belirlenmiştir. Kahire'de 19 hat ve 4 mercimek çeşidinde verim ve verim öğeleri arasındaki ilişkilerin belirlendiği çalışmada bitkide bakla sayısı, bitkide tane sayısı, bitki boyu ve bitkide tane veriminin hasat indeksini olumlu yönde etkileyen en önemli karakterler olduğu; tohum verimi ile bitki boyu, bitkide bakla sayısı, bitkide tohum sayısı, bitkide dal sayısı ve biyolojik verim arasında olumlu ilişiler bulunduğu, bunun yanında bitki boyu, bitkide dal sayısı ve bitkide bakla sayısı ile biyolojik verim arasında da kuvvetli ve olumlu ilişkiler olduğu Khattab (1999) tarafından ortaya konulmuştur.

Tablo 4. Yeşil mercimek çeşitlerinde incelenen özellikler arasındaki korelasyon katsayıları

	Bitki Boyu	İlk Bakla Yüksekliği	Biyolojik Verim	Ana Dal Sayısı	Bitkide Bakla Sayısı	Bitkide Tane Sayısı	1000 Tane Ağırlığı	Hasat İndeksi	Bitkide Tane Verimi	Dekara Tane Verimi
Bitki Boyu	**1,0000**	0,557**	0,271*	0,521**	0,311*	0,286*	0,562**	0,568**	0,410**	0,527**
İlk Bakla Yüksekliği	0,557**	**1,0000**	0,320*	0,269*	0,391*	0,330*	0,519**	0,388*	0,411**	-0,222*
Biyolojik Verim	0,271*	0,321*	**1,0000**	0,431**	0,714**	0,982**	-0,225	0,246	0,955**	0,263*
Ana Dal Sayısı	0,521**	0,269*	0,431**	**1,0000**	0,706**	0,388*	0,107	0,194	0,447**	0,645**
Bitkide Bakla Sayısı	0,311*	0,391*	0,714**	0,706**	**1,0000**	0,741**	-0,043	0,445**	0,774**	0,247*
Bitkide Tane Sayısı	0,286*	0,331*	0,982**	0,388*	0,741**	**1,0000**	-0,210	0,388*	0,978**	0,269*
1000 Tane Ağırlığı	0,562**	0,519**	-0,225	0,107	-0,043	-0,210	**1,0000**	0,505**	-0,016	-0,106
Hasat İndeksi	0,568**	0,388*	0,246	0,194	0,445**	0,388*	0,505**	**1,0000**	0,515**	0,231
Bitkide Tane Verimi	0,411**	0,412**	0,955**	0,447**	0,774**	0,978**	-0,016	0,515**	**1,0000**	0,286*
Dekara Tane Verimi	0,527**	-0,222*	0,263*	0,645**	0,247*	0,269*	-0,106	0,231*	0,286	**1,0000**

Bitkide bakla sayısı ile bitkide tane sayısı (r= 0.741**), hasat indeksi (r= 0.445**) ve bitkide tane verimi (r= 0.774**) arasında çok önemli ve olumlu; dekara tane verimi (r= 0.247*) ile önemli ve olumlu ilişkiler ortaya konulurken 1000 tane ağırlığı (r= -0.043) ile ise önemsiz fakat olumsuz ilişkiler saptanmıştır. Om ve ark. (2001), Hindistan koşullarında 2 farklı lokasyondan topladıkları geniş ve küçük taneli mercimeklerin melezlenmesi ile elde ettikleri 28 adet mercimek genotipinde özellikler arası ilişkilerin belirlenmesi amacıyla yürüttükleri araştırmalarında tane verimi ile hasat indeksi, bitkide bakla sayısı, bitki boyu ve tane ağırlığı arasında pozitif ve istatistiki olarak önemli bir ilişki bulunduğunu bildirmişlerdir.

Bitkide tane sayısı ile bitkide tane verimi (r= 0.978**) arasında çok önemli ve olumlu; hasat indeksi (r= 0.388*) ve dekara tane verimi (r= 0.269*) ile önemli ve olumlu ilişkiler belirlenirken 1000 tane ağırlığı (r= -0.210) ile ise önemsiz fakat olumsuz ilişkiler saptanmıştır. Chauhan ve Singh (2001), 21 adet mercimek genotipinin Hindistan'da 2 yıl süreyle 17 parametre açısından özellikler arası ilişkilerinin belirlenmesi üzerine yürüttükleri çalışmalarında tane veriminin, bakla sayısı, bitki boyu ve biyolojik verim ile olumlu ve güçlü bir korelasyon gösterdiğini bildirmişlerdir.

1000 tane ağırlığı ile hasat indeksi (r= 0.505**) arasında çok önemli ve olumlu ilişkiler bulunurken bitkide tane verimi (r= -0.016) ve dekara tane verimi (r= -0.106) ile ise önemsiz fakat olumsuz ilişkiler görülmüştür. Mercimekte verim özellikleri ile özellikler arası ilişkilerin belirlenmesi üzerine yürütülen çalışmada tane verimi ile bakla sayısı (0.814**), bin tane ağırlığı (0.248**), biyolojik verim (0.837**) ve hasat indeksi (0.483**) arasında olumlu ve güçlü ilişki belirlenirken; tane verimi ile bitki boyu (-0.053*) ve ilk bakla yüksekliği (-0.199*) arasında olumsuz ilişki görüldüğü; bakla sayısı (-0.238**) ve hasat indeksi (-0.335**) arasında ise olumsuz ancak güçlü bir ilişki bulunduğu Biçer ve ark. (2001) tarafından bildirilmiştir.

Hasat indeksi ile bitkide tane verimi (r= 0.515**) arasında çok önemli ve olumlu; dekara tane verimi (r= 0.231) ile ise önemsiz ve olumlu ilişkiler ortaya konulmuştur.

Bitkide tane verimi ile dekara tane verimi (r= 0.286*) arasında önemli ve olumlu ilişkiler belirlenmiştir. Vir ve Gupta (2002), Hindistan'da farklı lokasyonlarda 28 mercimek hattı ile yürüttükleri denemelerinde bitki verimi ile biyolojik verim, hasat indeksi, bakla sayısı, tane ağırlığı ve bitki boyu arasında pozitif ve önemli ilişkiler olduğunu saptamışlardır.

3.2. Path Analizi

Sivas ekolojik koşulları altında yürütülen çalışmada 10 adet yeşil mercimek genotipinde ele alınan 10 adet agronomik özelliğin dekara tane verimi üzerine doğrudan ve dolaylı etkilerini ve etki katsayılarını ortaya koyan veriler incelenmiş ve elde edilen sonuçlar Tablo 5'de verilmiştir. Gerçekleştirilen path analizlerinde ele alınan özelliklerin bazılarının negatif katsayıya sahip olmaları o özelliğin negatif yönde, pozitif katsayıya sahip olanların ise pozitif yönde gelişeceğini belirtmektedir.

Bitki boyunun dekara tane verimine doğrudan etki katsayısı (0.527) olarak belirlenmiş olup etki oranı %28.45 olarak ortaya konulmuştur. Bitki boyu en yüksek dolaylı etkiyi %19.56 ile bitkide bakla sayısı üzerinden göstermekle beraber bu dolaylı etkiyi bitkide tane sayısı (%16.43), ilk bakla yüksekliği (%13.95), bitkide tane verimi (%6.45) ve bin tane ağırlığı (%5.12) izlemiştir. Dekara tane verimine bitki boyu üzerinden en düşük dolaylı etkiyi ise %2.35 ile hasat indeksi üzerinden göstermiştir.

İlk bakla yüksekliğinin dekara tane verimine doğrudan etki katsayısı (-0.222) olarak belirlenmiş olup etki oranı %25.69 olarak ortaya konulmuştur. İlk bakla yüksekliği en yüksek dolaylı etkiyi %21.12 ile bitki boyu üzerinden göstermekle beraber bu dolaylı etkiyi biyolojik verim (%14.54) ve ana dal sayısı (%13.22) izlemiştir. Dekara tane verimine ilk bakla yüksekliği üzerinden en düşük dolaylı etkiyi ise bitkide tane verimi (%3.17) üzerinden göstermiştir.

Biyolojik verimin dekara tane verimine doğrudan etkisi (0.263) ile pozitif yönlü olurken en yüksek dolaylı etki miktarını bitkide tane verimi üzerinden (0.288) göstermiştir. Bunu bitki boyu (0.262) ve ilk bakla yüksekliği (0.239) izlemiştir. Etki oranları incelendiğinde biyolojik verimin dekara tane verimine doğrudan %20.29'luk bir oranla etki ederken en yüksek dolaylı etkiyi bitkide tane verimi (%18.66), bitki boyu (%16.47) ve ilk bakla yüksekliği (%12.85) üzerinden yapmıştır.

Ana dal sayısının dekara tane verimine doğrudan etki katsayısı (0.645) olarak pozitif yönde belirlenmiş olup etki oranı %16.11 olarak tespit edilmiştir. Ana dal sayısı en yüksek dolaylı etkiyi %20.18 ile bitki boyu üzerinden göstermekle birlikte bu dolaylı etkiyi bitkide bakla sayısı (%15.68) ve ilk bakla yüksekliği (%13.74) izlemiştir. Dekara tane verimine ana dal sayısı üzerinden en düşük dolaylı etkiyi ise bin tane ağırlığı (%3.12) üzerinden göstermiştir.

Bitkide bakla sayısının dekara tane verimi üzerine doğrudan etki katsayısı (0.247) olurken bunun oransal etki miktarı %22.25 olarak görülmüştür. Bunun dışındaki dolaylı etkiler de bitkide tane verimi hariç %15'in altında kalmıştır. Nitekim bitkide tane sayısı, bitki boyu ve ilk bakla yüksekliğinin bitkide bakla sayısı üzerinden dekara tane verimine dolaylı etkileri sırasıyla %12.85, %11.08 ve %11.27 olarak saptanmıştır. Bin tane ağırlığının bitkide bakla sayısı üzerinden yaptığı dolaylı etki %3.81 olarak görülmüş olup bin tane ağırlığının bitkide bakla sayısı üzerinden yaptığı dolaylı etki aslında bin tane ağırlığı azaldıkça bitkide bakla sayısının artacağı ve buna bağlı olarak dekara tane veriminin de artacağını belirtmektedir.

Bitkide tane sayısı bakımından doğrudan ve dolaylı etkiler incelendiğinde doğrudan etki katsayısının (0.269) olarak belirlendiği görülmüş olup etki oranının %25.66 olarak değer aldığı tespit edilmiştir. Dolaylı etki bakımından ise en yüksek etkiyi bitkide tane sayısı üzerinden dekara tane verim üzerine %23.63 ile bitkide tane verimi üzerinden yapmış olup bu özelliği %20.58 ile bitkide bakla sayısı izlemiştir. En düşük dolaylı etki ise %4.02 ile ana dal sayısında saptanmıştır.

Bin tane ağırlığının dekara tane verimine doğrudan etki katsayısı (-0.106) gibi negatif bir değere sahip olmuş olup bunun oransal karşılığı ise %22.68 olarak belirlenmiştir. Dolaylı etki bakımından ise en yüksek etkiyi bin tane ağırlığı üzerinden dekara tane verimi üzerine %18.45 ile bitkide tane verimi üzerinden yapmış olup bu özelliği %14.29 ile bitkide bakla sayısı ve %13.42 ile bitkide tane sayısı takip etmiştir. En düşük dolaylı etki ise %5.41 ile bitkide tane sayısında olduğu gibi ana dal sayısında gerçekleşmiştir.

Hasat indeksinin dekara tane verimine doğrudan etkisi (0.231) ile pozitif yönlü olurken en yüksek dolaylı etki miktarını biyolojik verim üzerinden (0.277) göstermiştir. Etki oranları incelendiğinde hasat indeksinin dekara tane verimine doğrudan %22.51'lik bir oranla etki ederken en yüksek dolaylı etkiyi bitkide tane verimi (%20.31), bitkide bakla sayısı (%12.25) ve bitkide tane sayısı (%11.48) üzerinden yapmıştır. Dekara tane verim üzerine hasat indeksi üzerinden en düşük dolaylı etki ise %5.51 ile ana dal sayısında belirlenmiş olup 5 adet agronomik özellik bitki boyu, ilk bakla yüksekliği, biyolojik verim, ana dal sayısı ve 1000 tane ağırlığı) dolaylı etkileri bakımından %10'un altında kalmışlardır.

Bitkide tane veriminin dekara tane verimine doğrudan etkisi (0.286) ile pozitif yönlü olurken en yüksek dolaylı etki miktarını bitkide bakla sayısı (0.266) göstermiştir. Etki oranları incelendiğinde bitkide tane veriminin dekara tane verimine doğrudan %27.02'lik bir oranla etki ederken en yüksek dolaylı etkiyi bitkide bakla sayısı (%17.28), bitkide tane sayısı (%15.25) ve hasat indeksi (%10.49) üzerinden yapmıştır. Dekara tane verim üzerine bitkide tane verimi üzerinden en düşük dolaylı etki ise %4.25 ile 1000 tane ağrılığında belirlenmiş olup 5 adet agronomik özellik (bitki boyu, ilk bakla yüksekliği, biyolojik verim, ana dal sayısı ve 1000 tane ağırlığı) dolaylı etkileri bakımından %10'un altında kalmışlardır.

Tablo 5. İncelenen öğelerin dekara tane verimi üzerinde doğrudan ve dolaylı etkileri

Doğrudan Etki	Dolaylı Etki	Doğrudan Etki Miktarı	Dolaylı Etki Miktarı	Etki Oranı (%)
Bitki Boyu		**0.527**		28.45
	İlk Bakla Yüksekliği		0.016	13.95
	Biyolojik Verim		0.248	3.44
	Ana Dal Sayısı		0.137	4.25
	Bitkide Bakla Sayısı		-0.095	19.56
	Bitkide Tane Sayısı		0.169	16.43
	1000 Tane Ağırlığı		0.219	5.12
	Hasat İndeksi		0.209	2.35
	Bitkide Tane Verimi		0.278	6.45
İlk Bakla Yüksekliği		**-0.222**		25.69
	Bitki Boyu		-0.182	21.12
	Biyolojik Verim		0.021	14.54
	Ana Dal Sayısı		-0.037	13.22
	Bitkide Bakla Sayısı		0.114	10.62
	Bitkide Tane Sayısı		0.129	8.78
	1000 Tane Ağırlığı		0.217	6.25
	Hasat İndeksi		0.229	4.33
	Bitkide Tane Verimi		0.246	3.17
Biyolojik Verim		**0.263**		20.29
	Bitki Boyu		0.262	16.47
	İlk Bakla Yüksekliği		0.239	12.85
	Ana Dal Sayısı		0.141	8.35
	Bitkide Bakla Sayısı		0.205	7.45
	Bitkide Tane Sayısı		0.233	6.93
	1000 Tane Ağırlığı		0.124	4.28
	Hasat İndeksi		0.159	4.72
	Bitkide Tane Verimi		0.288	18.66
Ana Dal Sayısı		**0.645**		16.11
	Bitki Boyu		0.254	20.18
	İlk Bakla Yüksekliği		0.268	13.74
	Biyolojik Verim		0.091	6.94
	Bitkide Bakla Sayısı		0.124	15.68
	Bitkide Tane Sayısı		0.129	9.91
	1000 Tane Ağırlığı		0.154	3.12
	Hasat İndeksi		0.102	4.77
	Bitkide Tane Verimi		-0.119	9.55
Bitkide Bakla Sayısı		**0.247**		22.25
	Bitki Boyu		-0.96	11.08
	İlk Bakla Yüksekliği		-0.112	11.27
	Biyolojik Verim		0.069	6.41
	Ana Dal Sayısı		0.143	7.25
	Bitkide Tane Sayısı		0.347	12.85

	1000 Tane Ağırlığı		-0.052	3.81
	Hasat İndeksi		0.162	7.66
	Bitkide Tane Verimi		0.369	17.42
Bitkide Tane Sayısı		**0.269**		25.66
	Bitki Boyu		-0.109	5.20
	İlk Bakla Yüksekliği		-0.136	4.02
	Biyolojik Verim		0.234	4.15
	Ana Dal Sayısı		0.171	3.57
	Bitkide Bakla Sayısı		0.195	20.58
	1000 Tane Ağırlığı		0.111	7.29
	Hasat İndeksi		0.104	5.90
	Bitkide Tane Verimi		0.296	23.63
1000 Tane Ağırlığı		**-0.106**		22.68
	Bitki Boyu		0.182	6.41
	İlk Bakla Yüksekliği		0.207	6.34
	Biyolojik Verim		0.047	7.29
	Ana Dal Sayısı		0.166	5.41
	Bitkide Bakla Sayısı		0.135	14.29
	Bitkide Tane Sayısı		0.118	13.42
	Hasat İndeksi		0.039	5.71
	Bitkide Tane Verimi		0.188	18.45
Hasat İndeksi		**0.231**		22.51
	Bitki Boyu		0.147	6.21
	İlk Bakla Yüksekliği		0.92	6.46
	Biyolojik Verim		0.277	9.49
	Ana Dal Sayısı		0.132	5.51
	Bitkide Bakla Sayısı		0.175	12.25
	Bitkide Tane Sayısı		0.120	11.48
	1000 Tane Ağırlığı		0.081	5.78
	Bitkide Tane Verimi		0.262	20.31
Bitkide Tane Verimi		**0.286**		27.02
	Bitki Boyu		-0.088	7.13
	İlk Bakla Yüksekliği		-0.156	7.21
	Biyolojik Verim		0.134	6.31
	Ana Dal Sayısı		0.107	5.06
	Bitkide Bakla Sayısı		0.266	17.28
	Bitkide Tane Sayısı		0.247	15.25
	1000 Tane Ağırlığı		-0.171	4.25
	Hasat İndeksi		0.162	10.49

4. SONUÇ

Yürütülen bu araştırma ile yeşil mercimekte dekara tane verim üzerine etkili olabilecek özelliklerin değişim aralıkları ortaya konulmuştur. Yeşil mercimekte çeşit geliştirme çalışmalarında bitkide tane verimi, bitkide bakla ve tane sayısı, bin tane ağırlığı, biyolojik verim ve bitki boyu özelliklerinin dikkate alınmasının önemli olduğu görülmüş olup seleksiyon çalışmalarında yürütülecek ıslah araştırmalarında seleksiyon kriterleri olarak ele alınacak bitkisel parametrelerin de belirlenmesinde path analizinin de etkili olabileceği belirlenmiştir. Ayrıca bitki boyu, ana dal sayısı, bitkide bakla ve tane sayısı ile bitkide tane verimi gibi agronomik özelliklerin incelenmesinde gerek yüksek gerekse olumlu ve dolaylı etkilerinden dolayı göz önüne alınmasının önemli olduğu da bu çalışma ile gerçekleştirilmiştir.

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BAZI MERCİMEK ÇEŞİTLERİNİN AGRO-MORFOLOJİK ÖZELLİKLERİNİN ORTAYA KONULMASI

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ÖZET
Bazı mercimek çeşitlerinin agro-morfolojik özelliklerinin belirlenmesi amacıyla Sivas ili ekolojik koşullarında 2024 yılında tarımsal AR-GE merkezinde mercimeğin vejetasyon döneminde tesadüf blokları deneme deseninde dört tekrarlamalı olarak yürütülen araştırmada 10 adet tescil edilmiş yeşil mercimek çeşidi materyal olarak yer almıştır. Yürütülen çalışmada agronomik özellikler olan bitki boyu (cm), ilk bakla yüksekliği (cm), biyolojik verim (g), ana dal sayısı (adet), bitkide bakla sayısı (adet), bitkide tane sayısı (adet), bin tane ağırlığı (g), hasat indeksi (%), bitkide tane verimi (g) ve dekara tane verimi (kg/da) özellikleri ele alınmıştır. Çalışma sonucunda yeşil mercimek çeşitlerinde dekara 82,95-124,00 kg arasında tane verimi değeri tespit edilmiş olup dekara tane verimine en yüksek Ankara Yeşili sahip olurken en düşük verim ise Pul-11 çeşidinde saptanmıştır. Yine çalışmada yeşil mercimek çeşitlerine bağlı olarak bitki boyunda 21,15-30,23 cm, bitkide bakla sayısında 20,75-33,50 adet, bitkide tane sayısında 13,25-36,50 adet, bin tane ağırlığında 28,88-33,60 g aralığında değerler elde edilmiştir. Sonuç olarak; Ankara Yeşili, Kafkas, Gümrah, Karagül, Meyveci 2001 ve Bozok çeşitlerinden elde edilen verim unsurlarına ait değerlerin diğer yeşil mercimek çeşitlerine göre daha yüksek oldukları ortaya konulmuştur.
Anahtar Kelimeler: Yeşil mrcimek, Çeşit, Verim, Agronomik özellikler

1. GİRİŞ

Kendi kendine döllenebilme kabiliyeti gösterebilen tek yıllık ve 2n=14 kromozomlu diploid bir yemeklik baklagil bitkisi olan Mercimek (*Lens culinaris* Medik.), dünya coğrafyasında kuzey (58^o) ve güney (40^o) enlemleri arasında bulunmakla beraber ülkemizde ise neredeyse hemen hemen her bölgede (Doğu Karadeniz kıyıları hariç) çiftçiler tarafından yetiştiriciliği yapılabilmektedir (Kantar, 2021).

Dünya üzerinde mercimek tarımının ne zaman başladığına dair yürütülen çalışmalarda yetiştiricilik başlangıcın Suriye, Türkiye, İran, Yunanistan ve Bulgaristan'da M.Ö 8000-5000 yıllarına kadar dayandığı görülmektedir (Sandhu ve Singh, 2007). Ülkemiz, mercimeğin iri ve orta iri taneli çeşitlerinin doğal gen merkezi olarak kabul edilen Akdeniz ve Yakın Doğu gen merkezlerinde bulunmaktadır (Akdağ, 1996). Nil Vadisi ile Avrupa ve Asya kıtalarında Neolitik dönem süresince ekim alanları hızlı bir şekilde artış göstermiş olan mercimek, M.S. 15. yüzyılda İspanyol tüccarları tarafından Şili üzerinden Güney Amerika'ya kadar götürülmüştür (Erskine, 1997).

Çok uzun yıllardır insan beslenmesinde yoğun bir şekilde kullanılan mercimek; enerji, protein, lif, vitaminler ve mineraller (Na, Cu, K, Mg, P, Ca, Fe, Mn, Zn) bakımından da zengin (Urbano ve ark., 2007) olmasının yanında tohumlarındaki %25 civarında protein içeriği ile baklagiller içerisinde soya fasulyesinden sonra en yüksek proteine sahip baklagil türü konumundadır.

Çözünür lif kaynağının yüksek olmasından dolayı mercimek bitkisinin aynı zamanda kolesterol düşürücü, kan şekerini dengeleyici ve tokluk hissini artırıcı etkileri göstermesi nedeniyle kilo önleyici özelliği de bulunmakta olup çözünür lif kaynağının yüksek olması nedeniyle kan çözünmez lif içeriği sayesinde kabızlığı önleyerek sindirim sistemi rahatsızlıklarının giderilmesine de yardımcı olduğu belirlenmiştir (Rehinan ve ark., 2004).

Tek yıllık vejetasyona sahip olan mercimek; soğuğa, kuraga ve yüksek sıcaklıklara dayanıklılık göstermesinin yanında toprak isteği bakımından fazla seçici olmamasından dolayı kuru tarım alanlarında bir tahıl bitkisi olan buğday ya da arpa ile ekim nöbetine girmekte olup insanların ve hayvanların beslenmesindeki öneminin yanında toprak verimliliğine olumlu katkısı ve yüksek kazanç getirisiyle tarımsal bakımdan çok önemli bir konumda bulunmaktadır. Hasat ve harman sonra geriye kalan sap/samanda çok az miktarda da olsa selüloz bulunabildiğinden hayvanların beslenmesinde oldukça önemli bir yem kaynağı olabilmektedir. Bunun yanında köklerindeki nodüllerle ortak yaşama girebilen, bir rhizobium türü olan "*Rhizobium leguminosarum*" ile beraber havanın serbest azotunu toprağa fiksleyebilen ve yetiştirildiği toprağın azot miktarını artırabilen bir yapıya sahiptir (Aydoğan ve ark., 2008).

Dünyada yemeklik tane baklagiller içinde 2023 yılı itibariyle ekim alanı bakımından %7.5, üretim bakımından ise %7.95 oranı ile kuru fasulye, nohut, börülce ve bezelyeden sonra beşinci sırada yer alan mercimeğin verim değerleri bakımından ise diğer yemeklik tane baklagillerle kıyaslandığında bakla ve bezelyeden sonra üçüncü sırada kendine yer bulmuştur (FAO, 2023). Mercimek dünya üzerinde ılıman veya yarı tropik bölgelere yayılmış kuraga dayanıklı bir yemeklik tane baklagil bitkisidir. Kuru tane olarak tüketilen mercimek, en çok Orta Doğu ülkeleri ile Batı-Orta-Güney Asya ülkelerinde üretilmektedir. FAO 2023 verilerine göre mercimeğin istatistik verileri incelendiğinde dünyada mercimek üreten kıtaların başında Asya (2.994.358 ton), ülkelerin başında ise Hindistan (1.620.000 ton) gelmektedir. Kıtalar arasında verim bakımından ilk sırayı Amerika Kıtası (1.375,2 kg/ha) almaktadır. FAO (2023) verilerine göre 50 ülkede mercimek yetiştiriciliği yapılmakta olup kıtalar bazında değerlendirildiğinde Avrupa ve Asya kıtalarında 16 ülkede, Afrika kıtasında 10 ve Amerika kıtasında 8 ülkede mercimek yetiştiriciliği uzun yıllardır

gerçekleştirilmektedir. Kıtalar bazında mercimek ekim alanları değerlendirildiğinde Asya kıtası 3.476.081 ha ile ilk sırada gelirken Asya kıtasının ilk sırada bulunmasında yine bir Asya ülkesi olan Hindistan büyük önem taşımaktadır ki Hindistan dünya mercimek ekim alanı bakımından ilk sırada gelmektedir.

Ülkemizde yetiştiriciliği yapılan yemeklik tane baklagillerde gerek ekim alanı gerekse üretim miktarında önemli düşüşler görülmekle birlikte 1989 yılında yemeklik tane baklagil ekim alanları toplamı 2 milyon hektarın üstündeyken 30 yıl içinde yaklaşık 883.482 hektara kadar azalma göstermiştir. Aynı şekilde 2.115.000 ton olan üretim miktarı da 1.220.244 ton seviyelerine kadar gerilemiştir. Bu durum mercimek ekiliş ve üretimine de yansımış olup 997.000 ha olan mercimek ekim alanı çok ciddi bir şekilde azalma eğimiyle 277.228 hektara, 1.040.000 ton üretim miktarı ise 353.000 ton seviyelerine kadar düşme eğilimi göstermiştir. Bun karşın yeşil mercimek ekim alanımız ise yaklaşık 39.000 ha, üretimimiz ise 43.000 ton seviyelerindedir. Yeşil mercimek ekim alanları ülkemizde Yozgat, Çorum, Kırşehir, Ankara ve Konya illerini kapsayan İç Anadolu Bölgesinde daha çok görülmektedir. Yeşil mercimeğin toplam mercimek üretim miktarı içerisinde aldığı pay yüzdesi yaklaşık olarak %7-8 arasında değişmektedir (TUİK, 2023).

Genotipik yapı ile çevre, en önemli verim unsuru olan tane veriminin ortaya konulmasında iki önemli faktör olup en uygun yetiştirme tekniklerinin belirlenmesi ile verim kabiliyeti yüksek çeşitlerin değişilebilir ekolojik şartlarda yetiştiriciliğinin yapılması ile gerek kaliteli gerekse yüksek ürün elde edebilmek için önemlidir. Mercimek yetiştiriciliğinin yapıldığı herhangi bir lokasyonda yüksek düzeyde verim elde edebilmek için ilk sırada bölgeye uygun çeşit/çeşitlerin yetiştirildiği bölge için seçimi şarttır ve çeşitlerin morfolojik/fizyolojik özelliklerin önceden belirlenmesi, belli çevre koşullarında genotipler içinden üstün verimli olanları seçmede temel oluşturmaktadır. Mercimek yetiştiriciliğinde iklim ve toprak istekleri dikkate alındığında ülkemizin büyük bir imkana sahip olduğu görülmektedir (Bozdemir, 2007).

Bazı mercimek çeşitlerinin Sivas ekolojik koşullarında tane verimleri ile verim unsurları yönünden performanslarının ortaya konulması bu çalışmanın amacını oluşturmaktadır.

2. MATERYAL ve METOT

2.1. Materyal

Bu araştırmanın tarla çalışmaları Sivas Bilim ve Teknoloji Üniversitesi'nin Tarımsal AR-GE Merkezinde yer alan deneme arazisinde 2024 yılı mercimek vejetasyon döneminde yürütülmüştür. Araştırmanın yürütüldüğü lokasyon deniz seviyesinden yaklaşık 1285 m yükseklikte, N39,720656 - E36,917248 konumunda bulunmaktadır (Şekil 1).

Şekil 1. Araştırmanın yürütüldüğü deneme arazisi

Araştırmada, ülkemizde Tarımsal Araştırmalar ve Politikalar Genel Müdürlüğüne bağlı Tarımsal Araştırma Enstitüleri tarafından tescil ettirilmiş olan 10 adet yeşil mercimek çeşidi kullanılmıştır (Tablo 1).

Tablo 1. Çalışmada kullanılan çeşitler ile tescil ettiren kuruluşlar

Mercimek Çeşitleri	Tescil Ettiren Kuruluş
Sultan	Geçit Kuşağı Tarımsal Araştırma Enstitüsü Müdürlüğü / Eskişehir
Ankara Yeşili	Tarla Bitkileri Merkez Araştırma Enstitüsü Müdürlüğü / Ankara
Kafkas	
Gümrah	
Karagül	
Meyveci 2001	
Bozok	
Çiftçi	
Ceren	
Pul 11	

2.2. Araştırma Yerinin İklim Özellikleri

Sivas ilinin mercimek yetiştirme dönemine ait uzun yıllar ortalaması (1980-2023) ile araştırmanın yürütüldüğü 2024 yılının meteorolojik değerleri incelendiğinde uzun yıllar ortalaması ile 2024 yılına ait aylık sıcaklık ortalamaları ve aylık toplam yağış değerleri arasında Nisan ayı hariç büyük bir farkın olmadığı belirlenmiştir. Bununla birlikte 2024 yılı aylık ortalama nisbi nem değerlerinin de uzun yıllar ortalamasıyla paralellik gösterdiği Tablo 2'de ortaya konulmuştur.

Tablo 2. Sivas ilinin 2024 yılı ile uzun yıllara ait iklim verileri

Aylar	Ortalama Sıcaklık (^{0}C)		Toplam Yağış (mm)		Ortalama Nisbi Nem (%)	
	2024	Uzun Yıllar	2024	Uzun Yıllar	2024	Uzun Yıllar
Nisan	13.9	8.9	11.2	56.9	52.85	44.8
Mayıs	13.1	13.5	60.0	60.9	63.71	61.5
Haziran	20.9	17.0	11.6	34.5	59.45	58.0
Temmuz	22.0	20.0	37.0	9.2	53.25	49.1
Ağustos	22.0	20.2	10.2	6.8	47.43	45.9
Toplam	-	-	130.0	168.3	-	-

2.3. Toprak Özellikleri

Çalışmanın yürütüldüğü deneme arazisinin toprak öğeleri incelendiğinde deneme parselinin toprağının alkali seviyesinin hafif (7.28), organik madde içeriğinin orta (%1.7), alınabilir fosfor (3.40) ve potasyum düzeyleri (93.59) bakımından orta, tuz seviyesinin tuzlu (%0.33) ve kireç içeriğinin ise kireçli (19.6) olduğu ortaya konulmuştur (Tablo 3).

Tablo 3. Deneme yeri toprağının fiziksel ve kimyasal özellikleri

Derinlik	0-30 cm
pH	7.28
Toplam Tuz (%)	0.33
Kireç (% CaCO3)	19.6
Organik Madde (%)	1.7
Fosfor (P2O5 kg/da)	3.40
Potasyum (K2O)	93.59

2.4. Yöntem

Yürütülen çalışma, Tesadüf Blokları Deneme Deseninde 4 tekerrürlü olacak şekilde kurulmuş olup parseller 5.0 m x 0.8 m= 4 m^2 olacak şekilde ayarlanmıştır. Mercimek çeşitlerin parsellere dağılımı tesadüfî olarak gerçekleştirilmiştir. Denemenin ekimleri 25 Nisan 2024 tarihinde tavlı toprağa gerçekleştirilmiştir. Ekimler 20 cm sıra aralığında 2-3 cm sıra üzerinde, her bir sıraya 150-200 adet tohum düşecek şekilde markörle açılan sıralara 3 cm derinliğe elle yapılmıştır. Her parsel 4 sıradan oluşmuştur. Yabancı otlarla mücadele etmek üzere ekimlerle beraber ekim sonrası ve çıkış öncesi yabancı ot ilacı uygulanmış ve tüm vejetasyon süresince 2 sefer çapa yapılmıştır. Her parsele eşit olarak dekara 15 kg DAP (2,7 kg N/da ve 6,9 kg P2O5/da) gübresi ekimle birlikte toprağa verilmiştir. Araştırmanın yürütüldüğü deneme alanındaki çeşitlerin hasadı, hasat olgunluğuna ulaştıkları dönem aralığı olan 25 Temmuz-10 Ağustos 2024 tarihleri arasında el ile yapılmıştır. Parseli oluşturan 4 sıradan her iki yandaki birer sıra ve sıra başlarından 50 cm'nin içerisinde bulunan bitkiler kenar tesiri olarak gözlem dışı bırakılarak bütün işlemler 4 m x 0.4 m = 1.6 m^2'lik alanlar üzerinden yapılmıştır. Her bir parselden hasat edilen bitkiler ayrı ayrı çuvallara konulup etiketlenerek hasat-harman sonrası gerekli ölçümler ve analizler yapılmak üzere Sivas Bilim ve Teknoloji Üniversitesi Tarım Bilimleri ve Teknoloji Fakültesi Tarla Bitkileri Bölümü'nün harman laboratuvarına getirilmiştir. Her parselden rastgele seçilen 10'ar bitkide bitki boyu, ilk bakla yüksekliği, biyolojik verim, ana dal sayısı, bitkide bakla sayısı, bitkide tane sayısı, bin tane ağırlığı, hasat indeksi, bitkide tane verimi ve dekara tane verimi değerleri saptanmış ve bunların ortalamaları alınarak bitki başına ortalama değerler hesaplanmıştır.

2.5. Verilerin Değerlendirilmesi

Çalışmadan elde edilen veriler varyans analizine tabi tutulmuş olup özelliklere ait eldeki veriler arasındaki farklılığın istatistiksel kontrolünde JUMP.13 istatistiki paket programı uygulanmıştır. Önemli çıkanlar arasındaki farklılığın hangi ya da hangilerinden kaynaklandığını belirlemek için ise LSD testi ($P>0.05$) uygulanmıştır.

3. ELDE EDİLEN BULGULAR ve TARTIŞMA

3.1. Bitki Boyu

Yürütülen çalışma sonucunda yeşil mercimek çeşitlerinde ortaya konulan bitki boyuna ilişkin veriler Tablo 4'de verilmiştir. Bir agronomik özellik olan bitki boyu bakımından elde edilen değerler incelendiğinde çeşitler arasında önemli derecede ($p<0.05$) istatistiki farklılığın olduğu görülmüş olup çeşitlerin bitki boyu değerlerinin 21.15-30.23 cm arasında değişim gösterdiği belirlenmiştir. Çalışmada en yüksek bitki boyu 30.23 cm ile Ankara Tarla Bitkileri Merkez Araştırma Enstitüsü Müdürlüğü tarafından geliştirilmiş olan Ankara Yeşili çeşidinde ortaya konulurken en düşük bitki boyu değeri ise yine aynı enstitü tarafından geliştirilmiş olan Karagül çeşidinde saptanmış olup çeşitlerin ortalama bitki boyu değerinin ise 24.85 cm olarak ölçüldüğü tespit edilmiştir. Batman ekolojik koşullarında kışlık olarak yetişebilecek mercimek çeşitleri ile bunların önemli tarımsal ve bitkisel özelliklerini belirlemek amacıyla 2019 yılı yetiştirme sezonunda tescil edilmiş olan 12 adet mercimek çeşidi (Altıntoprak, Çağıl, Çiftçi, Emre-20, Fırat-87,Kafkas, Özbek, Sazak, Seyran-96, Şakar, Tigris ve Yerli Kırmızı) ile yürütülen çalışmada çeşitlere ait bitki boyunun 30.20-39.77 cm arasında değişim gösterdiği Tekin (2019) tarafından ifade edilmiş olup bu özellik üzerine yürütülen diğer çalışmalarda Kaçar ve Azkan (1997) Bursa ekolojik koşullarında 19.9-27.9 cm, Bildirici ve Çiftçi (2001) Van ekolojik koşullarında 22.2-25.8 cm, Demirhan (2006) Siirt ekolojik koşullarında 31.8-48.5 cm, Bozdemir ve Önder (2009) Ankara ekolojik koşullarında 28.9-38 cm, Canbolat (2014) Kahramanmaraş ekolojik koşullarında 44.48-45.55 cm, Alabay (2019) Konya ekolojik koşullarında 25.03-29.83 cm ve Irmak (2023) Kırşehir ekolojik koşullarında 21.33-30.33 cm değerlerini elde etmişlerdir. Elde ettiğimiz değerlerin,

araştırmacıların elde ettiği bitki boyuna ait değerler arasında yer aldığı görülmekte olup yürütülen çalışmalarla benzerlik gösterdiği saptanmıştır.

3.2. İlk Bakla Yüksekliği

Yürütülen çalışmada ilk bakla yüksekliği bakımından yeşil mercimek çeşitleri arasındaki farklılık istatistiki yönden önemli bulunmamıştır. Yeşil mercimek çeşitlerinde ilk bakla yüksekliğine ilişkin ortalama değerler Tablo 4'de verilmiştir. Çizelge ilk bakla yüksekliği değerleri bakımından değerlendirildiğinde en yüksek ilk bakla yüksekliği 17.71 cm değeri ile Ceren çeşidinde tespit edilirken en düşük ilk bakla yüksekliği ise tıpkı bitki boyunda olduğu gibi 10.83 cm değeri ile Karagül çeşidinde belirlenmiş olup tüm yeşil mercimek çeşitlerinin ise ortalama ilk bakla yüksekliği değerinin 15.57 cm olarak ölçüldüğü ortaya konulmuştur. Farklı yıllarda yürütülen projeler ile çiftçilerden toplanarak seleksiyona tabi tutulan 48 adet yeşil mercimek hattı ile 5 adet yeşil mercimek çeşidinin 2023 yılında Kırşehir ekolojik koşullarında verim öğelerinin belirlendiği çalışmada mercimek genotiplerinin ilk bakla yükseklik değerlerinin 10.48 (M-16)-19.60 (M-47) cm aralığında değişim gösterdiği Irmak (2023) tarafından ifade edilmiş olup bu parametre üzerine yürütülen diğer çalışmalarda Stoilova ve Pereira (1998) Bulgaristan ekolojik koşullarında 7-25.8 cm, Türk ve Atikyılmaz (2000) Diyarbakır ekolojik koşullarında 14-30 cm, Erman ve ark. (2005) Siirt ekolojik koşullarında 10-16 cm, Demirhan (2006) Siirt ekolojik koşullarında 10.0-16.0 cm, Ölmez (2011) Adıyaman ekolojik koşullarında 3.65-5.42 cm, Canbolat (2014) Kahramanmaraş ekolojik koşullarında 25.31-25.84 cm, Güneş (2016) Kahramanmaraş ekolojik koşullarında 19.4-19.5 cm, Alabay (2019) Konya ekolojik koşullarında 11.33-12.16 cm ve Küçükay ve ark. (2019) Isparta ekolojik koşullarında 9.23-20.2 cm değerlerini sağlamışlardır. Araştırmacıların elde ettiği değerlerin yaptığımız çalışma ile benzerlik gösterdiği ortaya konulmuştur.

3.3. Biyolojik Verim

Yürütülen çalışmada biyolojik verim bakımından yeşil mercimek çeşitleri arasındaki farklılık istatistiki yönden çok önemli ($p<0.01$) bulunmuştur. Yeşil mercimek çeşitlerinde biyolojik verime ilişkin ortalama değerler Tablo 4'de verilmiştir. Biyolojik verim değerleri bakımından tablo incelendiğinde en yüksek biyolojik verim, 2.76 g değeri ile Bozok çeşidinde tespit edilirken en düşük biyolojik verim ise 1.14 g değeri ile Pul 11 çeşidinde saptanmış olup tüm yeşil mercimek çeşitlerinin ise ortalama biyolojik verim değerinin 2.016 g olarak tespit edildiği ortaya konulmuştur. Mardin-Kızıltepe Yayıklı köyünde 2020-2021 yetiştirme sezonunda 12 tescilli mercimek (Seyhan-96, Yerli Kırmızı, Fırat-87, Atakan, Özbek, Çağıl, Çiftçi, Şanlıbey, Şakar, Altın Toprak, Evirgen ve Tigris) çeşidinde verim ve verimle ilgili özelliklerin ortaya konulması amacıyla yürütülen çalışmada çeşitlerin biyolojik verim değerlerinin 712-877.3 kg/da aralığında değişim gösterdiği Yiğit (2023) tarafından ortaya konulmuş olup bu parametre üzerine yürütülen diğer çalışmalarda Şakar ve ark. (1997) Diyarbakır ekolojik koşullarında 3.00-9.40 g, Karadavut ve ark. (1999) Amik Ovası ekolojik koşullarında 2.69-4.33 g, Biçer ve ark. (2001) Diyarbakır ekolojik koşullarında 1.525-4.932 g, Bucak ve ark. (2003) Harran Ovası ekolojik koşullarında 3.36-4.64 g, Erman ve ark. (2005) Siirt ekolojik koşullarında 5.93-7.68 g, Kayan ve Adak (2006) Ankara ekolojik koşullarında 3.14-5.50 g, Biçer ve Şakar (2008a) Diyarbakır ekolojik koşullarında 2.93 g, Tyagi ve Khan (2011) Hindistan ekolojik koşullarında 6.4-6.5 g, Kayan ve Olgun (2012) Eskişehir ekolojik koşullarında 4.48 g, Canbolat (2014) Kahramanmaraş ekolojik koşullarında 3.41-3.82 g ve Alabay (2019) Konya ekolojik koşullarında 3.56 g, Küçükay ve ark. (2019) Isparta ekolojik koşullarında 223.8-506 kg/da, Tekin (2019) Batman ekolojik koşullarında 212.22-395.22 kg/da, Hakoymaz ve Önder (2022) Konya ekolojik koşullarında 388.61-505.97 kg/da ve Irmak (2023)

Kırşehir ekolojik koşullarında 4.21-7.91 g arasında değerleri elde etmişlerdir. Araştırmacıların elde ettiği değerlerin yaptığımız çalışma ile benzerlik gösterdiği ortaya konulmuştur.

3.4. Bitkide Ana Dal Sayısı

Yürütülen çalışmada bitkide ana dal sayısı bakımından yeşil mercimek çeşitleri arasındaki farklılık istatistiki yönden önemli bulunmamıştır. Yeşil mercimek çeşitlerinde ana dal sayısına ilişkin ortalama değerler Tablo 4'de verilmiştir. Tablo, ana dal sayısı değerleri bakımından değerlendirildiğinde en yüksek ana dal sayısı 2.48'er adet ile Ankara Yeşili ve Meyveci 2001 çeşitlerinde tespit edilirken en düşük ana dal sayısı ise 2.15 adet değeri ile Karagül çeşidinde belirlenmiş olup tüm yeşil mercimek çeşitlerinin ortalama ana dal sayısı değerinin ise 2.33 adet olarak ölçüldüğü ortaya konulmuştur. 1994-1995 yıllarını kapsayan mercimek üretim döneminde Malazgirt-89 mercimek çeşidinde en fazla tane verimi sağlayan ekim sıklığının tespit edilmesine yönelik yürütülen çalışmada bitkide ana dal sayısı değerinin 5.7 adet olduğu Ağsakallı ve Olgun (1999) tarafından bildirilmiş olup bu özellik üzerine yürütülen diğer çalışmalarda Günel ve ark. (1993) 1.77-2.05 adet, Sharma ve ark. (2013) 1.75-5.60 adet, Kaplan (2015) 1.76-2.36 adet, Zulkadir ve ark. (2015) 5.68-7.13 adet, Koç ve Akdeniz (2019) 3.8-4.8 adet, Irmak (2023) 1.00-2.00 adet ve Yiğit (2023) 2.5-3.7 adet arasında değerler elde etmişlerdir. Araştırmacıların elde ettiği değerlerin yaptığımız çalışma ile benzerlik gösterdiği ortaya konulmuştur.

3.5. Bitkide Bakla Sayısı

Çalışmada yer alan yeşil mercimek çeşitlerinin bitkide bakla sayısı üzerine etkisinin önemsiz olduğu araştırmada en yüksek bitkide bakla sayısı 33.50 adet ile Bozok yeşil mercimek çeşidinden elde edilirken sırasıyla Meyveci 2001 (33.25 adet) ve Ankara Yeşili (31.25 adet) mercimek çeşitleri Bozok mercimek çeşidini izlemiştir. Pul 11 mercimek çeşidi ise yeşil mercimek çeşitleri içinde 20.75 adet bitkide bakla sayısı değeri ile son sırada yer almış olup yeşil mercimek çeşitlerinin ortalama bitkide bakla sayısı değerinin ise 27.72 adet olarak elde edildiği görülmüştür. Isparta ili ekolojik koşullarında 11 adet mercimek çeşidinin verim ile bazı verim unsurlarını belirlemek amacıyla yürütülen çalışmada mercimek çeşitlerinin bitkide bakla sayısı değerlerinin 17.9-38.7 adet aralığında değişim gösterdiği Keskin (2021) tarafından rapor edilmiş olup bu özellik üzerine yürütülen diğer çalışmalarda Karadavut ve ark. (1999) Amik Ovası ekolojik koşullarında 20.16-33.90 adet, Biçer ve ark. (2001) Diyarbakır ekolojik koşullarında 12.1-43.8 adet, Erman ve ark. (2005) Siirt ekolojik koşullarında 9.5-34.5 adet, Demirhan (2006) Siirt ekolojik koşullarında 9.5-34.5 adet, Biçer ve Şakar (2007) Diyarbakır ekolojik koşullarında 22.5-41.1 adet, Bozdemir (2007) Ankara ekolojik koşullarında 10.3-15.1 adet, Güneş (2016) Kahramanmaraş ekolojik koşullarında 41.00-49.22 adet, Mekonnen ve ark. (2014) Etiopya ekolojik koşullarında 27.80-43.3 adet, Kaplan (2015) Van ekolojik koşullarında 17.8-24.3 adet, Doğanay ve ark. (2017) Yozgat ekolojik koşularında 25.9-43.4 adet, Toklu ve ark. (2017) Adana ve Sivas illeri ekolojik koşullarında sırasıyla 12.0-74.3 adet ile 10.8-113.6 adet, Alabay (2019), Konya ekolojik koşullarında 20.46-25.40 adet, Küçükay ve ark. (2019) Isparta ekolojik koşullarında 30.13-50.73 adet, Tekin (2019) Batman ekolojik koşullarında 12.07-28.07 adet, Ulukuş (2019) Nevşehir ekolojik koşullarında 9.21-440.62 adet, Doğan ve Doğan (2020) Mardin ekolojik koşullarında 14.7-29.0 adet, Kantar (2021) Kırşehir ekolojik koşullarında 36.08-41.08 adet, Keskin (2021) Isparta ekolojik koşullarında 17.9-38.7 adet, Yürürdurmaz ve ark. (2021) 18.73-42.10 adet, Irmak (2023) Kırşehir ekolojik koşullarında 28.83-34.33 adet ve Yiğit (2023) Mardin ekolojik koşullarında 12.2-35.5 adet arasında değerler elde etmişlerdir. Araştırmacıların elde ettiği değerlerin yaptığımız çalışma ile benzerlik gösterdiği ortaya konulmuştur.

Tablo 4. Mercimek çeşitlerinde verim ve verim özelliklerinin değerlerine ilişkin ortalamalar ile oluşan istatistikî gruplar

Çeşitler	Bitki Boyu	İlk Bakla Yüksekliği	Biyolojik Verim	Ana Dal Sayısı	Bitkide Bakla Sayısı
Ankara Yeşili	**30,23 a**	15,91	2,47 ab	**2,48**	31,25
Kafkas	26,05 ab	14,65	1,58 cd	2,45	24,25
Gümrah	22,73 bc	14,55	2,53 ab	2,35	29,25
Karagül	**21,15 c**	**10,83**	1,40 cd	**2,15**	23,50
Meyveci 2001	23,48 bc	16,28	1,91 bcd	**2,48**	33,25
Bozok	25,75 abc	17,20	**2,76 a**	2,45	**33,50**
Çiftçi	22,92 bc	15,48	2,41 ab	2,16	24,25
Ceren	27,23 ab	**17,71**	1,97 abc	2,25	27,50
Sultan	24,38 bc	16,45	2,01 abc	2,23	29,75
Pul 11	24,55 bc	16,68	**1,14 d**	2,18	**20,75**
Ortalama	**24,85**	**15,57**	**2,016**	**2,33**	**27,72**
Önemlilik	*	öd	**	öd	öd
CV (%)	12,81	10,67	10,47	13,60	10,83

3.6. Bitkide Tane Sayısı

Yeşil mercimek çeşitleri arasında bitkide tane sayısı bakımından farlılığın önemsiz bulunduğu çalışmada en yüksek bitkide tane sayısı 36.50 adet ile bitkide bakla sayısında olduğu gibi Bozok yeşil mercimek çeşidinde ortaya konulurken bu çeşidi sırasıyla Ankara Yeşili (33.25 adet) ile Gümrah (32.75 adet) mercimek çeşitleri izlemiştir. Yine bitkide bakla sayısında olduğu gibi Pul 11 yeşil mercimek çeşidi ise tüm mercimek çeşitleri içinde 13.25 adet bitkide tane sayısı değeri ile son sırada yer almış olup tüm yeşil mercimek çeşitlerinin ortalama bitkide tane sayısı değerinin ise 26.73 adet olarak saptandığı görülmüştür. Türkiye'de tescilli farklı kırmızı mercimek çeşitlerinin Isparta koşullarında verim ve verim öğelerinin belirlenmesi amacıyla 2016-2017 yetiştirme sezonunda yürütülen araştırmada mercimek çeşitlerinin bitkide tane sayısı değerlerinin 40.96-64.70 adet arasında değişim gösterdiği Küçükay (2019) tarafından ortaya konulmuş olup bu parametre üzerine yürütülen diğer çalışmalarda Gupta ve ark. (1996) Hindistan ekolojik koşularında 19-145 adet, Kaçar ve Azkan (1997) Bursa ekolojik koşullarında 10.4-16.5 adet, Stoilova (1998) Bulgaristan ekolojik koşullarında 9.7-75.5 adet, Şakar ve Biçer (2001) Diyarbakır ekolojik koşullarında 115.4-118.6 adet, Koç (2004) Diyarbakır ekolojik koşullarında 23.9-57.4 adet, Erman ve ark. (2005) Siirt ekolojik koşullarında 12.8-54.3 adet, Demirhan (2006) Siirt ekolojik koşullarında 12.8-54.3 adet, Kayan ve Adak (2006) Ankara ekolojik koşullarında 23-38 adet, Biçer ve Şakar (2007) Diyarbakır ekolojik koşullarında 33.1-57.9, Çokkızgın ve Anlarsal (2008) Kahramanmaraş ekolojik koşullarında 26.8-50.6 adet, Fikiru ve ark. (2010) Etiopya ekolojik koşullarında 77.3-466.9 adet, Biçer ve Şakar (2011) Diyarbakır ekolojik koşullarında 15.5-28.0 adet, Sözen ve Karadavut (2017) Kırşehir ekolojik koşullarında 10.7-18.5 adet, Toklu ve ark. (2017) Adana ve Sivas ekolojik koşullarında sırasıyla 1.33-34.6 adet ve 3.60-87.4 adet, Alabay (2019) Konya ekolojik koşullarında 20.40-24.13 adet, Alabay (2019) Konya ekolojik koşullarında 20.4-24.13 adet, Küçükay ve ark. (2019) Isparta ekolojik koşullarında 40.96-64.7 adet, Tekin (2019) Batman ekolojik koşullarında 20.12-47.28 adet, Doğan ve Doğan (2020) Mardin ekolojik

koşullarında 16.9-33.2 adet, Erman ve ark. (2022) Van ekolojik koşullarında 156-334 adet, Irmak (2023) 24.00-40.00 adet ve Yiğit (2023) Mardin ekolojik koşullarında 12.1 ile 39.7 adet arasında kalan değerler elde etmişlerdir. Araştırmacıların elde ettiği değerlerin yaptığımız çalışma ile benzerlik gösterdiği ortaya konulmuştur.

3.7. 1000 Tane Ağırlığı

Bin tane ağırlığı, verim öğeleri içinde önemli bir agronomik özellik olup bitki başına tane verimi üzerinden dekara tohum verimini ciddi derecede etkileyebilmektedir. Bu kapsamda yeşil mercimek çeşitlerinin bin tane ağırlık üzerine etkisinin çok önemli ($p<0.01$) bulunduğu çalışmada değişim aralığının 28.88-33.60 g olarak oluştuğu görülmüş olup en yüksek bin tane ağırlığı 33.60 g ile Pul 11 yeşil mercimek çeşidinden elde edilirken bu çeşidi 33.35 g ile Bozok ve 32.03 g ile Ankara Yeşili mercimek çeşitleri izlemiştir. Çalışmada en düşük bin tane ağırlığı ise 28.88 g ile Gümrah çeşidinde ortaya konulurken tüm mercimek çeşitlerinin ortalama bin tane ağırlığı değerinin 31.42 g olarak belirlendiği görülmüştür. 2014 yılı mercimek yetiştirme sezonunda 183 mercimek çeşidi ile Adana ve Sivas illeri koşullarında verim ve verim öğelerinin belirlenmesi üzerine yürütülen araştırmada mercimek çeşitlerinin bin tane ağırlık değerlerinin Adana ilinde 12.0-51.7 g ve Sivas ilinde 12.5-44.0 g olarak belirlendiği Toklu ve ark. (2017) tarafından ifade edilmiş olup bu özellik üzerine yürütülen diğer çalışmalarda Gupta ve ark. (1996) Hindistan ekolojik koşullarında 12.20-51.70 g, Şakar ve ark. (1997) Diyarbakır ekolojik koşullarında 24.80-35.80 g, Karadavut ve ark. (1999) Amik Ovası ekolojik koşullarında 34.86-48.26 g, Bayrak (2001) 32.50-34.10 g, Biçer ve ark. (2001) Diyarbakır ekolojik koşullarında 26.45-40.00 g, Karadavut ve ark. (2001) 39.45-60.35 g, Şakar ve Biçer (2001) Diyarbakır ekolojik koşullarında 23.40-47.80 g, Bucak ve ark. (2003) Harran Ovası ekolojik koşullarında 33.06-40.64 g, Çokkızgın ve Anlarsal (2008) 24.85-39.40 g, Bozdemir ve Önder (2009) Ankara ekolojik koşullarında 54.80-74.40 g, Ölmez (2011) Adıyaman ekolojik koşullarında 35.99-59.55 g, Güneş (2016) Kahramanmaraş ekolojik koşullarında 35.03-28.66 g, Alabay (2019) Konya ekolojik koşullarında 31.60-36.70 g, Tekin (2019) Batman ekolojik koşullarında 25.93-43.60 g ve Irmak (2023) Kırşehir ekolojik koşullarında 37.97-44.27 g değerlerini elde etmişlerdir. Araştırmacıların elde ettiği değerlerin yaptığımız çalışma ile benzerlik gösterdiği ortaya konulmuştur.

3.8. Hasat İndeksi

Yürütülen çalışmada hasat indeksi bakımından yeşil mercimek çeşitleri arasındaki farklılık istatistiki yönden önemsiz olup yeşil mercimek çeşitlerinde hasat indeksine ilişkin ortalama değerler Tablo 5'de verilmiştir. Hasat indeksi değerleri bakımından Tablo incelendiğinde en yüksek hasat indeksi %46.96 değeri ile Sultan çeşidinde tespit edilirken bu çeşidi %44.52 değeri ile Ceren ve %44.50 değeri ile Bozok çeşitleri izlemiştir. Çalışmada en düşük hasat indeksi ise %39.10 değeri ile Çiftçi çeşidinde belirlenmiş olup tüm yeşil mercimek çeşitlerinin ise ortalama hasat indeksi değerinin %42.06 olarak ölçüldüğü ortaya konulmuştur. Mercimekte verim özellikleri ile bu özellikler arası ilişkilerin belirlenmesi üzerine yürütülen çalışmada tane verimi ile hasat indeksi (0.483**) arasında olumlu ve güçlü ilişki belirlenirken; Çiçeklenme gün süresi ile hasat indeksi (-0.335**) arasında ise olumsuz ancak güçlü bir ilişki bulunduğu Biçer ve ark. (2001) tarafından rapor edilmiş olup bu özellik üzerine yürütülen diğer çalışmalarda Kaçar ve Azkan (1997) Bursa ekolojik koşullarında %18.80-33.70, Şakar ve ark. (1997) Diyarbakır ekolojik koşullarında %16.00-43.00, Karadavut ve ark. (1999) Amik Ovası ekolojik koşullarında %17.83-30.53, Biçer ve ark. (2001) Diyarbakır ekolojik koşullarında %24.00-29.00, Karadavut ve ark. (2001) %26.40-29.75, Erman ve ark. (2005) Siirt ekolojik koşullarında %25.10-38.70, Demirhan (2006) Siirt ekolojik koşullarında %25.10-38.70, Abdipur ve ark. (2011) İran ekolojik koşullarında %31.20, Ölmez (2011) Adıyaman ekolojik koşullarında %30.00-54.00, Tyagi ve Khan (2011)

Hindistan ekolojik koşullarında %32.00-32.8, Kayan ve Olgun (2012) Eskişehir ekolojik koşullarında %29.98, Sharma ve ark. (2013) Faizabad ekolojik koşullarında %24.11-42.13, Canbolat (2014) Kahramanmaraş ekolojik koşullarında %44.65-45.94, Küçükay (2019) Isparta ekolojik koşullarında %24.91-41.45, Tekin (2019) Batman ekolojik koşullarında %22.68-46.76, Keskin (2021) Isparta ekolojik koşullarında %28.40-40.00, Irmak (2023) Kırşehir ekolojik koşullarında %30.70-43.85 ve Yiğit (2023) Mardin ekolojik koşullarında %25.2-35.5 değerlerini sağlamışlardır. Araştırmacıların elde ettiği değerlerin yaptığımız çalışma ile benzerlik gösterdiği ortaya konulmuştur.

3.9. Bitkide Tane Verimi

Yürütülen çalışma sonucunda yeşil mercimek çeşitlerinden elde edilen bitkide tane verimine ait değerlerin 0.443-1.217 g arasında değişim gösterdiği belirlenmiş olup yeşil mercimek çeşitlerinin bitkide tane verim değerleri arasındaki farkların istatistiksel olarak çok önemli ($p<0.01$) olduğu görülmüştür. Bozok mercimek çeşidi, bitkide tane verimi bakımından en yüksek değere (1.217 g) sahip olurken bu çeşidi Ankara Yeşili (0.1.070 g) ve Sultan (0.948 g) izlemişlerdir. En düşük bitkide tane verim değeri ise 0.443 g ile Pul 11 yeşil mercimek çeşidinde belirlenmiş olup tüm yeşil mercimek çeşitlerinin ortalama bitki başına tane verim değerinin ise 0.841 g olduğu ortaya konulmuştur. Sivas ekolojik koşullarında bazı mercimek çeşitlerinin tarımsal öğelerinin ortaya konulması amacıyla 2022 yılında Sivas Bilim ve Teknoloji Üniversitesine ait araştırma deneme arazisinde mercimek vejetasyon döneminde tesadüf blokları deneme deseninde üç tekrarlamalı olarak yürütülen çalışmada 9 adet tescilli mercimek çeşidi (Sultan, Meyveci 2001, Pul 11, Ceren, Gümrah, Yusufhan, Bozok, Karagül ve Ankara Yeşili) kullanılmış olup mercimek çeşitlerinin bitkide tane verim değerlerinin 0.22 (Ankara Yeşili)-0.52 (Sultan) g aralığında değişim gösterdiği Karaköy ve Sözen (2023) tarafından belirlenmiş olup bu özellik üzerine yürütülen diğer çalışmalarda Stoilova (1998) Bulgaristan ekolojik koşullarında 1.1-9.5 g, Türk ve Atikyılmaz (2000) Diyarbakır ekolojik koşullarında 22.8-46.3 g, Bayrak (2001) 0.5-1.6 g, Biçer ve ark. (2001) Diyarbakır ekolojik koşullarında 0.512-2.070 g, Şakar ve Biçer (2001) Diyarbakır ekolojik koşullarında 2.32-24.88 g, Erman ve ark. (2005) Siirt ekolojik koşullarında 0.83-1.56 g, Demirhan (2006) Siirt ekolojik koşullarında 0.83-1.56 g, Biçer ve Şakar (2007) Diyarbakır ekolojik koşullarında 0.7-1.8 g, Çokkızgın ve Anlarsal (2008) Kahramanmaraş ekolojik koşullarında 0.682-1.645 g, Biçer ve Şakar (2011) Diyarbakır ekolojik ekolojik koşullarında 0.69 g, Kayan ve Olgun (2012) Eskişehir ekolojik koşullarında 29.95 g, Roy ve ark. (2013) Bangladeş ekolojik koşullarında 2.13 g, Sharma ve ark. (2013) Faizabad ekolojik koşullarında 0.92-6.62 g, Hussain ve ark. (2014) Pakistan ekolojik koşullarında 13.8-27.9 g, Katiyar ve Kent (2015) Hindistan ekolojik koşullarında 545 g, Küçükay ve ark. (2019) Isparta ekolojik koşullarında 0.49-2.07 g ve Irmak (2023) Kırşehir ekolojik koşullarında 1.81-2.42 g aralığında yer alan değerleri elde etmişlerdir. Bitkide tane verimi üzerine elde ettiğimiz değerlerin, araştırmacıların elde ettiği değerler arasında yer aldığı görülmekte olup yapılan çalışmalarla benzerlik göstermiştir.

Tablo 5. Mercimek çeşitlerinde verim ve verim özelliklerinin değerlerine ilişkin ortalamalar ile oluşan istatistikî gruplar

Çeşitler	Bitkide Tane Sayısı	Bin Tane Ağırlığı	Hasat İndeksi	Bitkide Tane Verimi	Dekara Tane Verimi
Ankara Yeşili	33,25	32,03 ab	44,18	1,070 ab	**124,00 a**
Kafkas	20,75	31,90 ab	42,09	0,663 cde	123,00 a
Gümrah	32,75	**28,88 c**	39,15	0,940 abc	101,40 b
Karagül	18,75	30,40 bc	40,81	0,575 de	101,30 b
Meyveci 2001	25,00	30,43 bc	40,03	0,760 bcd	100,30 b
Bozok	**36,50**	33,35 a	44,50	**1,217 a**	99,87 b
Çiftçi	31,75	29,77 bc	**39,10**	0,920 abc	98,77 bc
Ceren	27,25	32,07 ab	44,52	0,875 bcd	97,31 bc
Sultan	30,25	31,80 ab	**46,96**	0,948 abc	96,74 bc
Pul 11	**13,25**	**33,60 a**	39,49	**0,443 e**	**82,95 c**
Ortalama	**26,73**	**31,42**	**42,06**	**0,841**	**102,54**
Önemlilik	öd	**	öd	**	**
CV (%)	13,55	5,19	11,80	11,45	10,92

3.8. Dekara Tane Verimi

Yürütülen çalışma sonucunda yeşil mercimek çeşitlerinde belirlenen dekara tane verimine ilişkin değerler Tablo 5'de verilmiştir. Tablo incelendiğinde; yeşil mercimek çeşitlerinin dekara tane verim değerleri arasındaki farklar istatistiksel olarak çok önemli ($p<0.01$) bulunmuş olup çalışmada yer alan yeşil mercimek çeşitlerinin dekara tane verimi değerlerinin 82.95-124.00 kg/da arasında değişim gösterdiği ortaya konulmuştur. En yüksek dekara tane verimi Ankara Yeşili (124.00 kg/da) mercimek çeşidinden elde edilirken buna karşın en düşük dekara tane verim değeri ise Pul 11 (82.95 kg/da) mercimek çeşidinde görülmüş olup tüm mercimek çeşitlerinin ortalama dekara tane verim değerinin ise 102.54 kg/da olarak belirlendiği ortaya konulmuştur. Kahramanmaraş ekolojik koşullarında 2017-2018 yetiştirme yılında 10 farklı mercimek çeşidi kullanılarak bazı verim ve verim özelliklerinin belirlenmesi amacıyla yürütülen araştırmada mercimek çeşitlerinin tane verim değerlerinin 103.60-187.17 kg/da aralığında değişim gösterdiği Yürürdurmaz ve ark. (2021) tarafından ifade edilmiş olup bu özellik üzerine yürütülen diğer çalışmalarda Türk ve Atikyılmaz (2000) Diyarbakır ekolojik koşullarında 44.40-139.40 kg/da, Erman ve ark. (2005) Siirt ekolojik koşullarında 152.00-297.50 kg/da, Yıldız (2007) Güneydoğu Anadolu Bölgesi ekolojik koşullarında 214.61-345.00 kg/da, Karadeniz (2008) Mardin ekolojik koşullarında 44.13-201.76 kg/da, Aydın Ölmez (2011) Adıyaman ekolojik koşullarında 88.40-128.20 kg/da, Canbolat (2014) Kahramanmaraş ekolojik koşullarında 219.20-239.60 kg/da, Kaplan (2015) Van ekolojik koşullarında 74.60-122.00 kg/da, Güneş (2016) Kahramanmaraş ekolojik koşullarında 65.25-82.50 kg/da, Öktem (2016) Şanlıurfa ekolojik koşullarında 72.82-186.16 kg/da, Hakkoymaz (2018) Konya ekolojik koşullarında 116.23-140.02 kg/da, Kardeş (2019) Kırşehir ekolojik koşullarında 157.40-204.90 kg/da, Küçükay ve ark. (2019) Isparta ekolojik koşullarında 66.00-195.80 kg/da, Tekin (2019) Batman ekolojik koşullarında 49.78-173.33 kg/da, Sözen ve Yağmur (2020) Kırşehir ekolojik koşullarında 96.68-126.60 kg/da ve Erman ve ark. (2022) Van ekolojik koşullarında 57-155 kg/da aralığında yer alan değerleri elde etmişlerdir. Çalışmamızda bu

verim öğesi üzerine elde ettiğimiz değerler araştırmacıların dekara tane verim üzerine elde ettikleri değerler aralığında yer almakta olup çalışmamız ile paralellik göstermektedir.

4. SONUÇ

Bazı yeşil mercimek çeşitlerinin 2024 yılında Sivas ekolojik koşullarında verim ve verim öğelerinin performanslarının ortaya konulabilmesi amacıyla yürütülen araştırma sonuçlarına göre Bozok, Ankara Yeşili ve Gümrah yeşil mercimek çeşitlerinin Sivas ekolojik koşulları için uygun çeşit adayları oldukları ancak bu tür yapılacak performans kabiliyetlerinin belirlendiği adaptasyon çalışmalarında alınacak verilerden daha sağlam tavsiyelerde bulunulabilmesi için gerçekleştirilecek çalışmaların en az 2-3 yıl daha tekrarlanmasının gerekliliği sonucuna ulaşılmıştır.

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EVALUATION OF *SALIX BABYLONICA* WASTES AS ION EXCHANGERS AND RAW MATERIALS FOR ACTIVATED CARBON: INVESTIGATION OF METHYLENE BLUE REMOVAL FROM AQUEOUS SOLUTIONS

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ABSTRACT

Agricultural wastes have a great potential in terms of waste management as well as being sustainable and environmentally friendly. In this study, *Salix babylonica* wastes were used as natural ion exchangers and converted into value-added products by using them as carbon source in activated carbon production. The knowledge that the cell walls of these wastes contain amine groups, carboxyl groups and phenolic OH groups has revealed the idea that they can be used as natural cation exchangers. On the other hand, these wastes are also carbon-rich sources of lignocellulosic biomass and potential feedstock for activated carbon synthesis. Fourier transform infrared spectroscopy (FTIR), scanning electron microscopy (SEM), energy dispersive X-ray (EDX) and BET analyses were used to characterize the waste and synthesized activated carbon. As a result of the literature research, slow pyrolysis process at 800 °C was preferred to obtain higher pore and surface area and activated carbon with a surface area of 984.433 m^2/g was successfully synthesized. After the activated carbon synthesis process, methylene blue (MB) removal studies were carried out from aqueous solutions to evaluate the properties of both materials. Taguchi method was applied through Minitab 22.1.0 statistical software program in the experimental design and data optimization processes. Concentration (20-100 mg/L), pH (2-11), dosage (1-20 g/L), temperature (30-70 ^oC) and time (15-180 min) were determined as independent variables and their effects on methylene blue removal were investigated. As a result of the experiments performed under different conditions, methylene blue removal percentages were calculated by UV-spectrophotometer. Under optimum experimental conditions, 98.875% methylene blue removal efficiency was achieved with natural cation exchanger and 100% with synthesized activated carbon. Optimum experimental conditions and efficiencies for both materials were evaluated comparatively.

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Keywords: *Salix Babylonica, Cation Exchanger, Activated Carbon, Methylene Blue, Taguchi Method.*

INTRODUCTION

Scientists have been very concerned about the toxic nature of dyes in recent years. Especially the dye-containing wastewater generated as a result of industrial activities is discharged into natural water bodies such as rivers and lakes. However, dyestuffs are mostly toxic and pose a threat to living organisms in water bodies, especially to soil and other living organisms. Therefore, the removal of dyestuffs from wastewater is an important issue and should be studied in this context (Garg & Chopra, 2022).

It is known that approximately 100 tons/year of dyes are released into water resources worldwide, but even pmm level of dye content is quite dangerous for living organisms. Techniques such as adsorption membrane separation, chemical oxidation, photocatalytic degradation, electrochemical methods, coagulation are used to remove dyes from wastewater (Eren et al., 2024).

Agricultural wastes, especially cellulose-containing wastes, have the ability to adsorb various pollutants. Lignocellulosic materials contain cellulose as well as other components such as hemicellulose and lignin. In addition to being abundant in nature, they are suitable materials for the removal of pollutants from wastewater with their advantages such as low cost and environmental friendliness. In addition to being used for adsorption by showing biosorbent properties, their low ash content and high carbon content make them potential raw materials for activated carbon synthesis. Among agricultural wastes, olive wastes, sugar beet bagasse, rice bagasse, peanut shells are biomass sources that have already been used in adsorbent production in literature studies (Lade et al., 2023)

Salix babylonica is a deciduous tree species and waste leaves occupy the soil and are disposed of by incineration. Being rich in carbon, *Salix babylonica* wastes are lignocellulosic biomass resources that can be utilized in industrial processes. On the other hand, the cell walls of *Salix babylonica* leaves show ion exchange properties. A review of the literature suggests that cell walls are low cross-linked cation exchangers. It has also been reported that there are four types of ion exchangers in the cell wall of the leaves, three cation exchangers and one anion exchanger, two types of carboxylic acids and a phenolic group attributed to α-D-galacturonic acid (Terebova et al., 2018).

Based on these properties, the idea of synthesizing activated carbon, a material that attracts attention with its high adsorption capacity, by using *Salix babylonica* waste as raw material and using the raw form of the waste as an ion exchanger was created. Methylene blue is one of the hazardous dyes in wastewater. In the rest of the study, the effect of both materials on methylene blue removal will be examined. Taguchi method was applied to determine the optimum conditions for adsorption and to reduce the number of experiments.

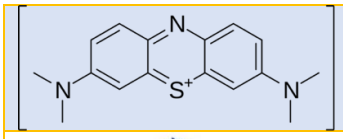
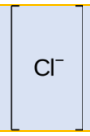
MATERIALS AND METHODS

Preparation

Waste *salix babylonica* leaves were collected and left to dry at 25^{o}C laboratory environment. The dried leaves were sieved using a 50-mesh sieve after grinding.

Methylene blue stock solutions at concentrations of 1000 ppm and 100 ppm were prepared for adsorption studies. Some properties of methylene blue are given in Table 1.

Table 2. Properties of Methylene blue dye (Lillie et al., 1977; Rahmani et al., 2020)

		**Formula**	**Cl name, number**	**Dye type**	**Molecular weight (g/mol)**	**λ_{max} (nm)**
Common name; **Methylene blue**		**$C_{16}H_{18}ClN_3S$** ***IUPAC name;*** 3,7-bis(Dimethylamino)-phenothiazin-5-ium chloride	Basic blue 9, 52015,	Cationic	319.85 g·mol^{-1}	640

Design of Experiments

Taguchi method, one of the statistical analysis methods, was applied to find the optimum experimental conditions in adsorption studies. Statistical approach is an effective method to reduce labor and process costs by reducing the number of experiments. Temperature, pH, adsorbent dosage, initial concentration and time are effective parameters in adsorption studies. Upon examining the effect of these parameters, 5 levels were determined for 5 factors and an experiment set consisting of 25 experiments was formed by applying L25 Taguchi orthogonal array. Factors and levels are given in Table 2.

Table 3. Taguchi method factors and levels

Factor	**Levels**	**Levels**
pH	5	2; 4.25; 6.5; 8.75; 11
Concentration	5	20; 40; 60; 80; 100
Dosage	5	1; 5; 10; 15; 20
Temperature	5	30; 40; 50; 60; 70
Time	5	15; 45; 90; 135; 180

Adsorption Studies

After the pre-treatments, the experimental process is divided into two stages. The first stage is the process in which the ion exchange properties of the crude form of *salix babylonica* wastes are examined. UV adsorbance of methylene blue solutions prepared at 1, 2, 3, 4 and 5 ppm concentrations were measured and calibration curve was created. Then, after pH adjustment of the solutions prepared at the desired concentration with HCl and NaOH, the adsorbent was added at the desired dosage and shaken in a shaker with temperature and time adjustment. At the end of the time, adsorbance measurements were taken after dilution and % methylene blue removal rates were calculated.

The second step is the process of synthesizing activated carbon from *Salix babylonica* waste by slow pyrolysis. Chemical activating agent $ZnCl_2$ and leaf powders were mixed in a 1:1 ratio. In an inert nitrogen environment, the pyrolysis furnace temperature was set at 15^{o}C/minute to 400 and 600 degrees Celsius for 15 minutes and 800 degrees Celsius for 80 minutes to complete the carbonization process. At the end of the carbonization process, activated carbon was dried at 80 degrees for 24 hours after washing with 5M HCl and washing and filtering with pure water 3 times.

The set of 25 experiments determined by Taguchi method was carried out by adjusting pH, dosage, concentration, time and temperature in the same way as the process in leaf powders. After dilution at the end of the process, % methylene blue removal was calculated with the help of the calibration curve equation generated by UV spectrometer (Figure 1.)

Figure 1. Experimental process

Adsorption capacity was calculated with the help of the equations given below. In the equation (qe) is the equilibrium adsorption capacity, (R) is the removal efficiency, Co (mg/L) is the initial concentration, Ce (mg/L) is the final concentration and V (L) is the volume (Acharya et al., 2020).

$$q_e = \frac{(C_0 - C_e)}{w} \quad (1)$$

$$R = \frac{(C_0 - C_e)100}{C_0} \quad (2)$$

FINDINGS

The results of FTIR analysis performed to determine the functional groups in the structure are given in Figure 2.

The FTIR spectrum of *Salix babylonica* waste is shown in Figure 2a. When the spectrum is examined, the broad peak observed at 3298.37 cm^{-1} symbolizes the presence of an alcohol group. This peak is associated with OH stress vibrations of pectin, cellulose and lignin-like alcohols, phenols and carboxylic acids in the leaf powder (Gouamid et al., 2013).

The peak at 2919.03 cm^{-1} corresponds to C-H stretching gradients, the peak at 2851.33 cm^{-1} corresponds to the symmetric stretching vibration of CH2, the peak at 1613.77 cm^{-1} corresponds to the stretching vibration of C=O, the peak at 1457.47 cm^{-1} corresponds to the carboxylic acid group.

The sharp peak at 1033.38 cm^{-1} corresponds to the C-O-C tension of cellulose in the structure (Han et al., 2010). These functional groups showed that *Salix babylonica* wastes are suitable for the retention of cationic dye.

When the activated carbon FTIR spectrum was analyzed, the peak at 2987.24 cm-1 seen in the spectrum in Figure 2c corresponds to C-H stress gradients. The peak at 2672.61 cm^{-1} is associated with OH-strain vibrations of pectin, cellulose and lignin-like alcohols, phenols and carboxylic acids. The peaks at 1993.32 cm^{-1} and 1885.95 cm^{-1} correspond to the C=O stretching vibration, the peak at 1560.439 cm^{-1} corresponds to the carboxylic acid group, and the sharp peak at 1101.93 cm^{-1} corresponds to the C-O-C tension of cellulose in the structure. The spectrum obtained from FTIR analysis after methylene blue adsorption is given in Figure 2.d (Han et al., 2010; Venkatesan et al., 2025).

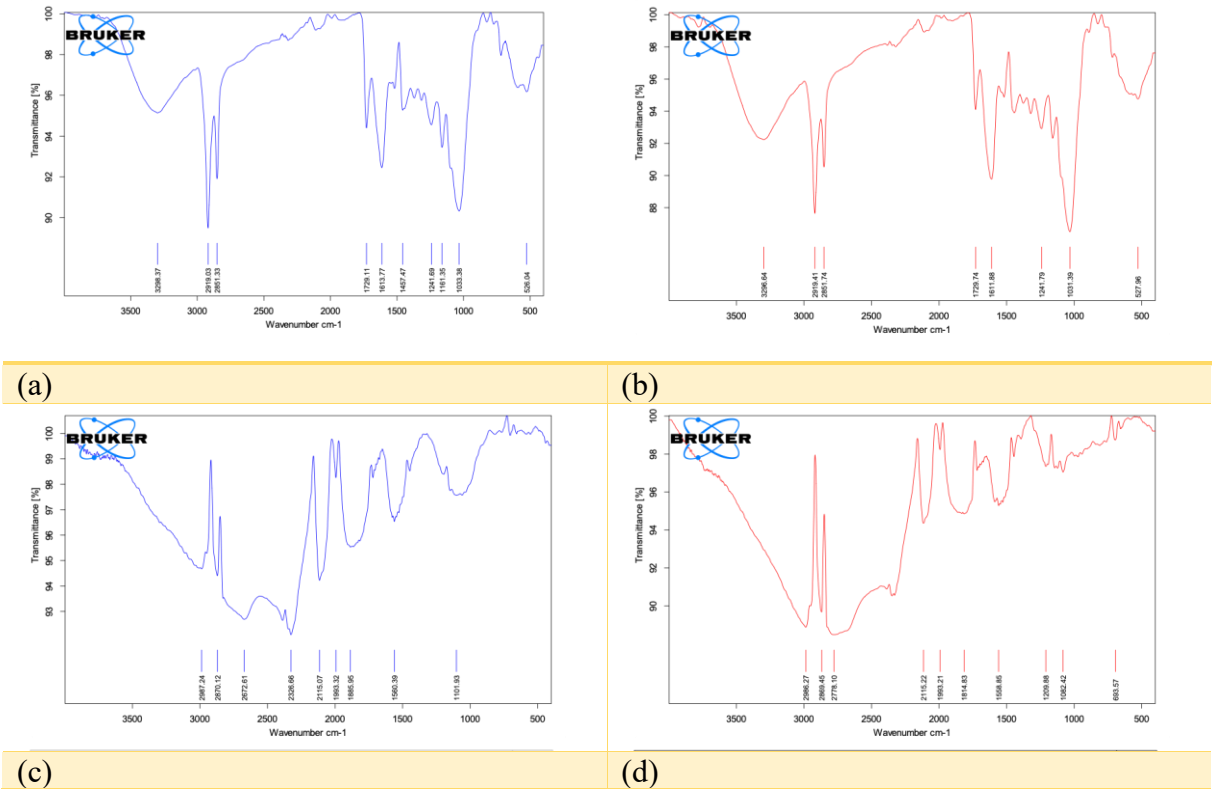


Figure 2. FTIR spectra a)willow leaves, b)willow leaves after methylene blue adsorption, c)activated carbon, d)activated carbon after methylene blue adsorption

SEM images of willow leaves and activated carbon before and after adsorption are shown in Figure 3. The SEM image of willow leaves before adsorption shows the presence of active sites favorable for adsorption and that the structure is porous. SEM images of activated carbon also showed that a highly porous material was synthesized. In the images after adsorption, it is seen that the surface becomes smoother as the pores on the surface are occupied by dye molecules. This proves that adsorption has taken place (Han et al., 2010; Mosoarca et al., 2022).

BET analysis was applied to measure the surface area and pore diameter of activated carbon. According to the results, it was determined that the activated carbon had a specific surface area of 984.433 m^2/g.

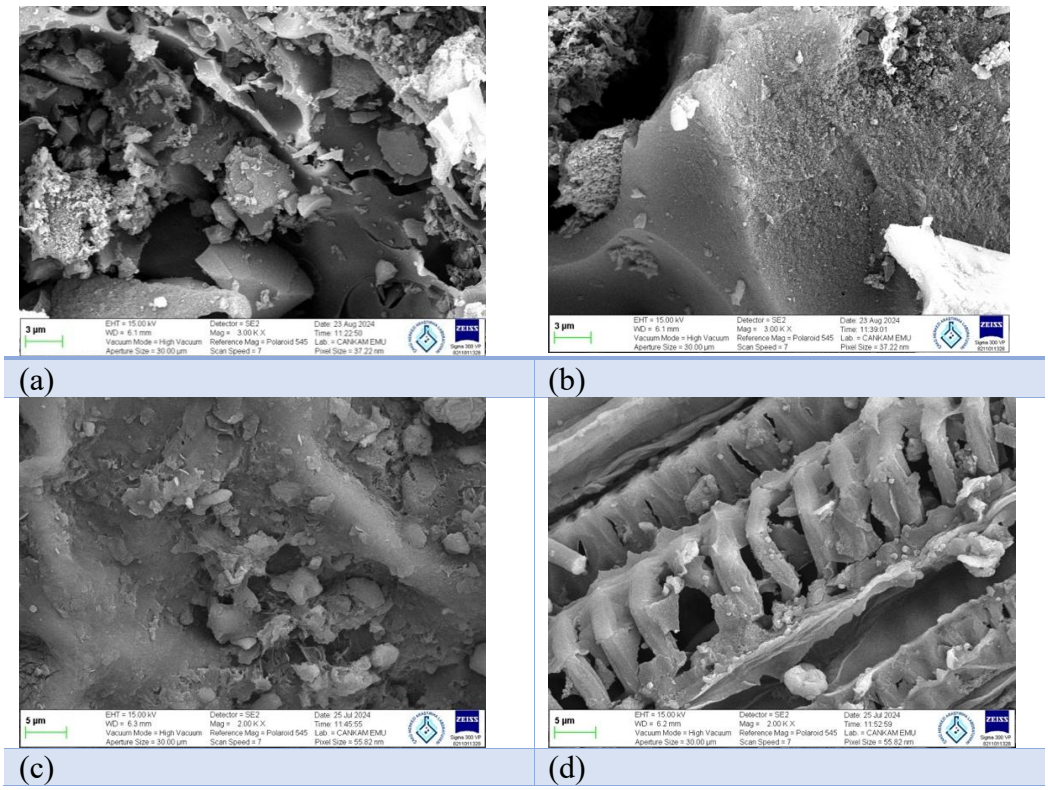


Figure 3. SEM images a) willow leaves, b) willow leaves after methylene blue adsorption, c) activated carbon, d) activated carbon after methylene blue adsorption

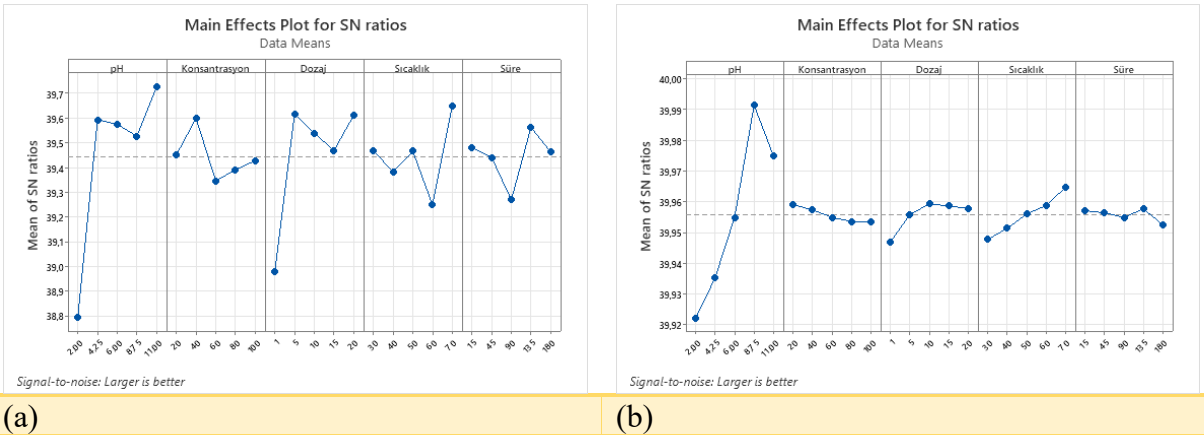


Figure 4. Effect of factors on dye removal percentages a) ion exchanger b) activated carbon

Figure 4 shows that higher pH values are more effective in the removal of methylene blue for both materials. With increasing pH, the medium becomes more basic, the surface is more negative and this negativity increases the electrostatic attraction between the adsorbent and the dye. As a result, higher pH values were more effective for both materials. The second effective factor was temperature. Increasing the temperature facilitated adsorption and the adsorption mechanism was

found to be endothermic. Adsorption increases with increasing dosage, while low initial concentrations are more effective in adsorption (Dabagh et al., 2024).

RESULTS AND DISCUSSION

In this study, ion exchange properties of *Salix babylonica* wastes were tested and activated carbon was synthesized from the wastes. The synthesized activated carbon has a very high specific surface area of 984.433 m^2/g. The removal of methylene blue, a cationic dye, from wastewater was studied with both materials. The optimum experimental conditions for the ion exchanger were determined as pH 11, concentration 100 ppm, dosage 15 g/L, temperature 50°C and contact time 45 minutes after performing 25 experiments determined by Taguchi statistical analysis method. For activated carbon, the optimum conditions were pH 8.75, concentration 80 ppm, dosage 5 g/L, temperature 70°C and contact time 90 minutes. Under these conditions, 98.875% methylene blue was removed by ion exchanger and 100% by activated carbon. Temperature and pH were determined as the most effective parameters in the adsorption process. It was concluded that the adsorption mechanism for both materials was endothermic. The fact that adsorption was more effective at high pH values showed that the adsorption process was sensitive to certain pH values.

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CHANGING TRENDS IN PEA CULTIVATION IN TÜRKIYE

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ABSTRACT
This study aims to analyze the spatial and temporal dynamics of pea cultivation in Türkiye between 2018 and 2023 by examining data on sown area, production quantity, and yield at the provincial level. Due to its high protein content, nitrogen-fixing ability, and low-input cultivation structure, pea is a strategic pulse crop for both human nutrition and sustainable agriculture. However, pea production in Türkiye has shown fluctuating trends over the years due to climatic variability, rising input costs, and marketing challenges. Analyses based on data from the Turkish Statistical Institute indicate that both cultivated area and production declined until 2020, followed by a recovery trend starting in 2021. This rebound may be associated with improving market prices, agricultural support policies, and more favorable weather conditions. Konya, Bursa, and Çankırı emerged as leading provinces in terms of both cultivated area and production volume, while traditional growing regions such as İzmir and Manisa experienced marked declines. In terms of productivity, the national average yield in 2023 was recorded at 321 kg da^{-1}, with Kilis leading at 500 kg da^{-1}. The findings reveal significant regional disparities in pea production, with concentration in certain provinces. To ensure sustainable pea cultivation, region-specific agricultural policies should be developed, irrigation infrastructure improved, drought-tolerant local varieties promoted, and farmer cooperatives strengthened.
Keywords: Pea production, sustainable agriculture, Türkiye, pulse crops, climate change

1. INTRODUCTION

Legume cultivation holds strategic importance globally, both for human nutrition and the sustainability of agricultural systems. Pea (*Pisum sativum* L.) is one of the most significant members of this group due to its high protein content, its ability to enhance soil fertility through nitrogen fixation, and its wide range of uses (Ceyhan, 2012). In addition to its role in ensuring food security, pea has a strong potential for cultivation even in climate-sensitive regions, owing to their ecological adaptability and suitability for low-input production systems (FAO, 2020; IPCC, 2022). Bozoğlu et al. (2014) also emphasize the strategic importance of pea in Türkiye, both in terms of human consumption and its potential for use in feed and industrial applications.

Despite Türkiye's rich agroecological diversity, it faces challenges related to continuity and productivity in the cultivation of food legumes such as peas (Ceyhan, 2012; Bozoğlu et al., 2014). Pea cultivation areas and production volumes have followed a fluctuating trend over the years (TURKSTAT, 2025). Significant declines have been observed in certain years, due to producers shifting toward alternative crops, adverse climatic changes, rising production costs, and marketing challenges (Kadakoğlu & Karlı, 2022). This situation has led to problems in meeting domestic demand and in enhancing competitiveness in foreign markets. Bozoğlu et al. (2014) state that pea production in Türkiye remains below its potential and that this gap could be closed through well-structured and effective planning policies.

Pea production in Türkiye is geographically concentrated in certain regions. Provinces such as Konya, Bursa, and Çankırı have recently emerged as leading areas in terms of both cultivation area and production. In contrast, traditional production regions like İzmir, Manisa, and Bartın have experienced notable declines (TURKSTAT, 2025). This divergence is closely related to multifaceted factors such as the development of agricultural infrastructure, availability of irrigation, farmer preferences, and local agrarian policies (Yıldız & Sel, 2023). The increase in production in arid and semi-arid areas such as Konya has been made possible through the dissemination of techniques suitable for legume cultivation. Ceyhan (2012) supports this view, noting that regional differences in pea production are strongly shaped by agroecological adaptation and sensitivity to cultivation practices.

Climate change is one of the most significant environmental factors that directly impacts pea production. Rising temperatures, irregular rainfall, and drought events, particularly during 2020 and 2021, led to declines in pea yield across Türkiye (IPCC, 2022; TSMS, 2025). However, the subsequent increase in yield observed after 2022 may be associated with the adoption of agricultural technologies, the use of high-yielding varieties, and better determination of optimal sowing times. In this context, understanding the reasons behind regional yield differences and identifying scalable best practices is of great importance.

The economic sustainability of pea cultivation in Türkiye is directly linked not only to production volume but also to productivity, cost-efficiency, and market structure (Ceyhan, 2012). In recent years, rising input costs and inadequate planning have caused producers to move away from legume cultivation, increasing dependence on imports and weakening the competitiveness of domestic producers (Kadakoğlu & Karlı, 2022). Strategies such as increasing the effectiveness of agricultural subsidies, promoting contract farming models, and improving market access could help reverse these negative trends.

Pea cultivation also plays an essential role in supporting rural development and enhancing the income levels of small-scale farmers. The success achieved in high-yielding provinces can serve as a model for other regions through the development of replication programs. In this process, improving irrigation infrastructure, ensuring the availability of suitable varieties, facilitating

knowledge and technology transfer, and expanding agricultural advisory services are of critical importance (Gül & Işık, 2002; FAO, 2020). Additionally, Önder and Ceyhan (2011) identify key challenges faced by legume producers in Türkiye, including limited market access, high input costs, insufficient support systems, and lack of knowledge, and emphasize the necessity of restructuring agricultural policies at the local level to address these issues.

This study aims to examine the changes in the area of pea cultivation, production, and yield across provinces in Türkiye between 2018 and 2023. Furthermore, it seeks to analyze the reasons behind geographical disparities, develop recommendations for production planning, and discuss the policy measures needed to ensure sustainable pea cultivation. Within the scope of the study, data from TURKSTAT were used for temporal comparisons, and the findings were interpreted in light of the relevant literature.

2. PEA CULTIVATION AREA IN TÜRKIYE

Data from the 2018–2023 period reveal that pea cultivation areas in Türkiye have followed a fluctuating trajectory over time. In 2018, the total cultivation area stood at 9,065 decares but experienced a significant decline in 2019 and 2020, dropping to 7,813 and 5,517 decares, respectively. This decrease was likely driven by producers shifting toward more profitable or lower-risk alternative crops, climate variability, rising input costs, or marketing difficulties (FAO, 2020; IPCC, 2022). However, beginning in 2021, the trend reversed, and the cultivated area increased steadily, reaching 11,832 decares in 2023—the highest level recorded in the past six years (Table 1). This recovery may be attributed to rising market prices and renewed producer interest (Gül & Işık, 2002).

At the provincial level, certain regions have emerged as key areas for pea cultivation. Konya, for example, expanded its cultivated area from just 950 decares in 2019 to 3,235 decares by 2023, becoming the province with the largest pea cultivation area. This growth may be linked to the availability of extensive farmland, well-developed irrigation infrastructure, and increasing interest in legume cultivation among farmers. Similarly, Bursa consistently increased its cultivation area from 2019 onward, reaching 2,753 decares in 2023, reaffirming the Marmara Region's importance in pea production. Notably, Çankırı, which had no recorded pea cultivation until 2021, entered production with 550 decares in 2022 and rapidly expanded to 2,450 decares in 2023. This remarkable growth is likely driven by local agricultural policies and farmer support initiatives (Ceyhan, 2012) (Table 1).

In contrast, some provinces have experienced notable declines in the area of pea cultivation over the years. İzmir, for instance, had high production figures in 2018 and 2019 (both years recording 2,920 decares), but this fell sharply to only 312 decares by 2023. This decline may be attributed to pressures from urbanization and industrial expansion, irrigation issues, or the adverse effects of climate change (FAO, 2020; IPCC, 2022). In other provinces such as Bartın, Kilis, and Manisa, pea production has fluctuated with no sustained upward trend. In these areas, production remains limited to small-scale, traditional farming systems. The group of provinces categorized as “Other” contributed a combined total of 867 decares in 2018, which decreased to 476 decares in 2023, indicating an increasing concentration of pea production in specific regions (Table 1).

Table 1. Pea Cultivation Areas in Türkiye (da)

	Years					
Provinces	2018	2019	2020	2021	2022	2023
Konya	2271	950	1250	2380	2860	3235
Bursa	980	925	918	1743	2442	2753
Çankırı					550	2450
Balıkesir	725	757	680	715	845	865
Çanakkale	218	467	515	498	488	640
Adana				14	355	395
İzmir	2920	2920	759	244	282	312
Kilis	330	300	250	240	250	270
Bartın	250	250	260	255	260	230
Manisa	504	404	405	204	205	206
Other	867	840	480	493	336	476
Total	9065	7813	5517	6786	8873	11832

(TURKSTAT, 2025)

Overall, although there has been a general resurgence in pea cultivation in recent years, this growth has been limited to a few provinces, resulting in a geographical imbalance. Provinces such as Konya, Bursa, and Çankırı have come to dominate national production, while several traditional production regions, including İzmir, have experienced rapid decline. This situation underscores the need for regionally targeted planning, appropriate cultivar selection, farmer training programs, and improved marketing strategies to ensure the sustainability of pea cultivation (Yıldız & Sel, 2023). Moreover, the promotion of climate-resilient varieties, support for small-scale producers, and strategies to increase competitiveness with alternative crops could help expand pea farming to a broader geographic area and enhance production stability (FAO, 2020; IPCC, 2022).

3. PEA CULTIVATION PRODUCTION IN TÜRKIYE

In Türkiye, total pea production declined steadily from 2,603 tons in 2018 to 1,538 tons by 2020. This contraction was likely due to structural factors such as adverse climatic conditions, low market prices, producers shifting toward alternative crops, and rising production costs. However, beginning in 2021, production began to recover, reaching 3,798 tons in 2023, marking the highest production level in the six years and indicating a significant rebound in pea cultivation (Table 2). This increase occurred in parallel with both the expansion of cultivated areas and improved yield per unit area, likely reflecting the influence of favorable weather conditions and the broader adoption of agricultural technologies (FAO, 2020; IPCC, 2022).

According to 2023 data, the highest contributions to pea production came from the provinces of **Bursa** (1,229 tons) and **Konya** (1,208 tons). While Bursa contributed only 250 tons in 2018, it increased its output fivefold within six years, accounting for nearly one-third of the national production. Konya, which already had a strong presence with 795 tons in 2018, experienced a temporary decline in 2020 but rebounded by 2023, maintaining its position as one of the leading producers. The rise in production capacity in these two provinces is attributed to both expanded cultivation areas and favorable agroecological conditions (FAO, 2020; IPCC, 2022). Additionally, provinces such as **Çankırı**, which have only recently become active in pea cultivation, have shown notable growth, increasing from 118 tons to 490 tons in just two years (Table 2).

Table 2. Pea Production in Türkiye (tons)

Provinces	Years					
	2018	2019	2020	2021	2022	2023
Bursa	250	225	216	327	563	1229
Konya	795	378	425	772	931	1208
Çankırı					118	490
Balıkesir	172	179	159	203	249	258
Çanakkale	54	113	126	121	119	151
Kilis	132	120	100	108	125	135
İzmir	915	911	322	94	71	79
Adana				2	71	79
Bartın	53	54	56	57	60	51
Manisa	65	53	53	27	27	28
Other	167	160	81	94	58	90
Total	2603	2193	1538	1805	2392	3798

(TURKSTAT, 2025)

Conversely, some provinces experienced sharp declines in production. For instance, **İzmir**, which had a high output of 915 tons in 2018, saw its production drop drastically to just 79 tons in 2023. This dramatic decline can be explained by a reduction in cultivated area, urban expansion, decreasing water resources, or farmers withdrawing from pea cultivation due to economic concerns. In **Manisa** and **Bartın**, production remained very limited throughout the period, contributing only marginally to national totals. The group of provinces classified under "**Other**" contributed 167 tons in 2018, decreasing to 90 tons by 2023, reflecting a similar declining trend (Table 2). These developments indicate that pea production in Türkiye is becoming increasingly concentrated in fewer provinces (FAO, 2020; IPCC, 2022).

These trends show that while pea production is expanding in certain key provinces, traditional production regions are experiencing a significant decline. This suggests an urgent need to reassess regional agricultural policies to ensure the sustainability of pea cultivation. In provinces with high production potential but underutilized capacity (e.g., **Adana** and **Çanakkale**), strategies such as improved irrigation infrastructure, access to quality seed, farmer training, and market support should be prioritized. Additionally, region-based production planning, informed by yield analysis and the promotion of climate-resilient varieties, is essential (Yıldız & Sel, 2023). Provinces such as Konya, Bursa, and Çankırı could serve as model regions, enabling a more balanced national distribution of pea production.

4. PEA CULTIVATION YIELD IN TÜRKIYE

In 2018, the average pea yield in Türkiye was recorded at 287 **kg da^{-1}**. This figure showed a limited downward trend in the following years, decreasing to 266 **kg da^{-1}** by 2021. This decline can be attributed particularly to drought conditions in 2020 and 2021, inadequate irrigation water, and region-specific yield reductions. However, starting in 2022, a recovery phase began, with the national average yield rising to 321 **kg da^{-1}** by 2023 (Table 3). This increase may be associated with improvements in the quality of agricultural inputs, favorable climatic conditions, and possibly the effective implementation of varietal improvement programs (FAO, 2020; IPCC, 2022). This rise in the national average yield is a positive indicator of productivity.

According to 2023 data, the province of Kilis stood out with the highest pea yield in the country at 500 **kg da^{-1}**. In this province, productivity has continuously increased since 2018, and

production is carried out on small plots with high efficiency. Nevşehir and Konya also performed above the national average, with yields of 400 **kg da^{-1}** and 373 **kg da^{-1}**, respectively (Table 3). Konya, in particular, holds strategic importance due to its leading position in terms of both cultivated area and total production. The high productivity in these provinces can be explained by factors such as soil structure, irrigation practices, the use of suitable varieties, and the effectiveness of production techniques (FAO, 2020; IPCC, 2022). Such regions can be considered as exemplary application zones and play a central role in agricultural education and technology transfer activities targeting other areas.

In contrast, provinces such as Balıkesir, İzmir, Kütahya, Çanakkale, and Bartın generally recorded yields below or close to the national average. For example, in 2023, yields were recorded at 298 **kg da^{-1}** in Balıkesir, 253 **kg da^{-1}** in İzmir, and only 236 **kg da^{-1}** in Çanakkale. In particular, İzmir has experienced a significant decline in yield despite higher levels in previous years (e.g., 424 **kg da^{-1}** in 2020 compared to 253 **kg da^{-1}** in 2023). This decline may be due to shrinking cultivation areas, water scarcity, urban pressure, or soil fatigue. Bartın consistently showed low productivity throughout the six years, reaching only 222 **kg da^{-1}** in 2023. This situation highlights the inadequacy of regional production conditions (Table 3).

Table 3. Pea Yield in Türkiye (kg da^{-1})

Provinces	Years					
	2018	2019	2020	2021	2022	2023
Kilis	400	400	400	450	500	500
Bursa	255	243	235	188	231	446
Nevşehir					333	400
Konya	350	398	340	324	326	373
Hatay	308	300	294	300	311	326
Balıkesir	237	236	234	284	295	298
İzmir	313	312	424	385	252	253
Kütahya	294	267	308	250	263	240
Çanakkale	248	242	245	243	244	236
Bartın	212	216	215	224	231	222
Mean of Türkiye	287	281	279	266	270	321

(TURKSTAT, 2025)

These findings indicate that the potential for pea production in Türkiye varies significantly by region. In high-yielding provinces, it is thought that there are successful practices in terms of production techniques, seed quality, and water management. In this context, in provinces with low productivity, the dissemination of agricultural extension services, promotion of modern irrigation systems, and the use of high-yielding local varieties should be prioritized. Additionally, preserving soil health and implementing crop rotation systems can sustainably increase productivity. National agricultural policies should be restructured to include not only measures to increase production volume but also structural support aimed at improving productivity, which is essential for the long-term success of pea farming in Türkiye (FAO, 2020; IPCC, 2022).

5. CONCLUSION AND EVALUATION

Within the scope of this study, pea cultivation in Türkiye during the 2018–2023 period was evaluated in terms of sown area, production, and productivity, with spatial differences at the provincial level highlighted. The data show a notable contraction in pea cultivation areas until

2020, followed by a reversal of this trend starting in 2021, resulting in renewed growth in production. This recovery is believed to be influenced by multiple factors, including the restructuring of producer support policies, particularly input subsidies, partial improvements in meteorological conditions, and increasing market demand, which made prices more attractive. Additionally, the increased interest in legume products resulting from the COVID-19 pandemic's impact on agricultural food supply chains may have contributed to this production motivation.

Provincial-level analyses reveal that Konya, Bursa, and Çankırı have emerged as leading regions in pea production, both in terms of cultivated area and total output. As of 2023, Konya became the largest production center in Türkiye, with a cultivated area of 3,235 decares and a production volume of 1,208 tons. This success is attributed to the province's extensive agricultural land, high level of mechanization, advanced irrigation infrastructure, and institutionalized farmer interest in legume farming. Bursa, on the other hand, has shown remarkable development by increasing its production fivefold over six years, reestablishing the Marmara Region's strategic importance in pea agriculture. Meanwhile, provinces like Çankırı, which entered production later but experienced rapid growth, reflect the effective implementation of local policies, agricultural support programs, and farmer training efforts.

On the opposite end, provinces such as İzmir and Manisa stand out with their declining trends. In particular, İzmir's cultivated area decreased from 2,920 decares in 2018 to only 312 decares in 2023, while production fell from 915 tons to 79 tons over the same period. This decline can be attributed to the shrinking of agricultural lands under pressure from urbanization, industrialization, and the tourism sector. Moreover, increasing water scarcity and irrigation costs have driven farmers away from water-sensitive crops like peas. Similar trends are observed in Manisa and Bartın, where production remains limited and competitiveness is weak. This highlights the severe sustainability challenges faced by traditional production regions, necessitating urgent intervention.

In terms of productivity, Türkiye experienced a decline in average yield during the drought-affected years of 2020 and 2021. However, by 2023, the national average yield rose to 321 kg da^{-1}, the highest level of the past six years. This positive development is directly linked to improved agricultural input quality, the spread of irrigation technologies, and increased use of disease-resistant and high-yielding varieties. Kilis achieved the highest yield in the country with 500 kg da^{-1}, while provinces like Konya, Bursa, and Nevşehir also performed well above the national average. In these regions, good agricultural practices, mechanization, and access to information appear to play a critical role in production success.

In contrast, low productivity levels in provinces such as Bartın, Çanakkale, and Kütahya suggest that structural agricultural problems are a determining factor. Persistently below-average yields in these regions indicate fundamental challenges such as inadequate irrigation infrastructure, low soil fertility, limited access to high-quality seeds, and a lack of technical knowledge among farmers. Additionally, the absence of crop rotation and lack of awareness regarding soil health maintenance also contribute to low productivity. In these areas, it is essential to expand agricultural extension services, provide locally adapted varieties, and deliver training on modern farming techniques.

To ensure the sustainability of pea production, Türkiye must restructure its regional agricultural planning. In regions with high but underutilized production potential, investments in irrigation should be increased, contract farming models should be encouraged, and the use of local seeds should be promoted. Furthermore, developing and disseminating climate-resilient varieties that offer high yields within short growing periods is of great importance (IPCC, 2022; FAO, 2020).

In this process, effective coordination among universities, research institutes, and provincial directorates of agriculture is recommended, alongside the establishment of evidence-based decision-making mechanisms.

In conclusion, pea farming in Türkiye is shaped by environmental, structural, and economic factors. The findings show that production is becoming spatially concentrated in certain provinces; however, without strategic planning, such concentration could jeopardize sustainability. The success observed in provinces like Konya and Bursa can be replicated in other regions through appropriate support policies. In this context, strengthening producer organizations, enhancing agricultural support mechanisms, improving marketing chains, and establishing science-based decision support systems are essential. In this way, pea production can play a crucial role in ensuring food security and make a significant contribution to revitalizing rural economies.

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THE LAST FIVE YEARS OF FABA BEAN CULTIVATION IN TÜRKIYE: TRENDS IN AREA, PRODUCTION, AND YIELD

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ABSTRACT
Faba bean is a legume species of strategic importance in agricultural systems due to its high protein content, its contribution to soil fertility through biological nitrogen fixation, and its diverse usage as a food and forage crop. Despite its agronomic and ecological advantages, faba bean cultivation in Türkiye has been on a significant decline over the past five years. This study aims to analyze the temporal changes in faba bean cultivation area, total production, and yield between 2018 and 2023 using official statistical data. The results revealed that the total cultivation area decreased from 25,294 hectares in 2018 to 17,554 hectares in 2023, corresponding to a reduction of more than 30%. Similarly, national production fell from 5,903 tons to 4,268 tons during the same period, reflecting a 27.7% drop. Although average yield slightly increased from 233 kg da^{-1} to 243 kg da^{-1} over the study period, this 4.3% rise was insufficient to compensate for the losses in area and output. The findings suggest that structural problems such as rising input costs, inadequate policy support, labor shortages, and market uncertainties, as well as climate change-induced stress (e.g., drought, irregular precipitation), have collectively contributed to this decline. The regional analysis further indicated significant inter-provincial disparities. While provinces such as Mersin and Muğla exhibited substantial improvements in yield, others like Tokat, Hatay, and Kütahya continued to record yields below the national average. This research highlights the urgent need for region-specific agricultural planning, yield-enhancing technologies, and adaptive strategies to climate change. Strengthening the sustainability of faba bean production is essential not only for conserving agrobiodiversity but also for securing rural livelihoods and national food security in Türkiye. The results serve as a data-driven basis for policymakers, agronomists, and rural development stakeholders to redesign targeted support programs for underutilized legume crops such as faba bean.

Keywords: Faba bean cultivation, cultivation area change, climate change, agricultural sustainability

1. INTRODUCTION

Legumes hold strategic importance in agricultural production systems due to their high protein content, ability to enhance soil fertility through nitrogen fixation, and critical role in human nutrition (Bozoğlu et al., 2014; FAO, 2020). Among this group, the faba bean (*Vicia faba* L.) stands out for its versatile uses, being consumed both as a green vegetable and as a dry pulse. Furthermore, the faba bean is well-suited to low-input production systems, has strong adaptation potential to varying soil and climate conditions, and contributes to the livestock feed industry (Akçin, 1988). Although faba bean has historically been cultivated widely across various regions of Türkiye, its cultivation area and production volume have recently declined, pushing the crop into a more marginal position.

Despite its integral role in traditional Turkish cuisine, faba bean cultivation has shown a marked decline in recent years, both in terms of producer interest and production statistics. The total cultivation area, which reached 25,294 decares in 2018, had decreased to 17,554 decares by 2023 (TURKSTAT, 2024). This roughly 30% reduction in area has led to a corresponding decline in total production, which dropped from 5,903 tons to 4,268 tons over the same period. Gül and Işık (2002) noted the long-term instability of legume production in Türkiye and the decreasing competitiveness of Turkish pulses in global markets. Structural challenges such as the decline in rural labor, rising input costs, and insufficient government support have adversely affected faba bean farming (Kadakoğlu & Karlı, 2022; Önder & Ceyhan, 2011).

The decline in faba bean production is not limited to the reduction in cultivation area; productivity levels have also shown only modest improvement. The national average yield per decare increased from 233 kg da^{-1} in 2018 to merely 243 kg da^{-1} in 2023 (TURKSTAT, 2024). This minimal yield improvement is primarily attributed to environmental stresses induced by climate change, such as drought, extreme temperatures, and irregular rainfall, as well as the limited adoption of modern agricultural practices (IPCC, 2022; TSMS, 2025). Moreover, yield disparities between provinces are substantial. Provinces like Mersin and Muğla exhibit high productivity, whereas Tokat, Hatay, and Kütahya show relatively low yields. These differences highlight the significant impact of local agricultural policies, infrastructure conditions, and farmer education on productivity.

Faba bean production in Türkiye is geographically concentrated in certain provinces. Çanakkale, Balıkesir, Kütahya, Muğla, and Manisa are notable for their extensive cultivation areas and high production volumes. However, even in these leading provinces, significant declines have been observed over the past five years. For instance, in Çanakkale, the cultivation area contracted by 33.8%, while production decreased by 30%. Conversely, provinces such as Muğla, Zonguldak, and Tokat have shown either increases or stability, indicating the importance of locally resilient production systems. These variations can be attributed to microclimatic advantages, the persistence of agricultural traditions, and the role of small-scale family farms (Bozoğlu et al., 2014; Yıldız & Sel, 2023).

The primary objective of this study is to evaluate the changes in faba bean cultivation in Türkiye over the past five years in terms of area (da), production (tons), and yield (kg/da), and to analyze the underlying causes of these changes through a regional lens. Issues such as sustainability in agricultural production, yield improvement, climate adaptation, and farmer welfare demand multidisciplinary approaches that encompass not only economic but also ecological and social dimensions. In this context, presenting current trends based on quantitative data will serve as a valuable resource for policymakers, agricultural economists, and producer organizations.

Furthermore, the findings of this analysis can help shape the future of crops like faba bean, which face the risk of marginalization in the national agricultural production system.

2. FABA BEAN CULTIVATION AREA IN TÜRKIYE

In Türkiye, the total area cultivated with faba bean reached 25,294 decares in 2018 but has shown a consistent decline in the following years, dropping to 17,554 decares by 2023 (Table 1). This reduction of more than 30% reflects a shift by producers away from traditional crops like faba bean towards alternative crops that promise higher income. Gül and Işık (2002) emphasized that legume production in Türkiye has followed an unstable trajectory over the long term, with declining competitiveness in international markets. The reduction in faba bean production has been linked to several structural problems, including the declining rural agricultural labor force, an aging farmer population, rising input costs, and uncertainties in marketing channels (Kadakoğlu & Karlı, 2022). In addition, water scarcity and the increasing impacts of climate change, as highlighted by FAO (2020) and IPCC (2022), present serious challenges to the cultivation of faba bean, which is predominantly grown under rainfed conditions. The downward trend observed, especially between 2018 and 2021, poses a critical issue not only for agricultural productivity but also for rural development and food security.

At the provincial level, Çanakkale has maintained its status as the leading province in Türkiye for faba bean cultivation. However, the cultivation area in this province declined from 6,720 decares in 2018 to 4,449 decares in 2023—a reduction of 33.8%. Similar substantial declines have been observed in Balıkesir and Kütahya (Table 1). These provinces were once prominent faba bean producers due to favorable climatic conditions, land structure, and traditional farming practices. In recent years, however, producers appear to have shifted towards other crops (Önder & Ceyhan, 2011). Bozoğlu, Ceyhan, and Karaköy (2014) point out that market assurances and support policies heavily influence producer preferences; when these mechanisms are ineffective, traditional crops tend to be abandoned. Additionally, the rising costs of fuel, fertilizers, and seeds have imposed financial pressure, particularly on small- and medium-scale producers.

The Aegean Region provinces of İzmir and Manisa exhibited fluctuating faba bean cultivation trends between 2018 and 2023. In İzmir, the cultivated area dropped to only 454 decares in 2020, before rising sharply to 1,501 decares in 2023 (Table 1). This sudden increase may be attributed to temporary agricultural subsidies, favorable market prices, or suitable seasonal conditions. In contrast, Manisa experienced a steadier decline, with cultivation area falling from 2,360 decares in 2018 to 1,320 decares in 2023. According to the IPCC (2022), climatic factors such as rising temperatures and declining precipitation in the Mediterranean basin, where Türkiye is located, pose serious threats to agricultural production. Ceyhan (2012) notes that although small-scale farmers in the Aegean Region strive to maintain traditional crops, market volatility and labor shortages make sustainable production increasingly difficult. These dynamics demonstrate that both environmental and economic factors shape local production decisions.

Provinces like Bartın, Zonguldak, Muğla, and Tokat, though contributing less to national faba bean output, have shown more stable cultivation trends. For example, Bartın's cultivated area declined only slightly from 830 decares in 2018 to 790 decares in 2023, while Tokat maintained a stable 200 decares from 2018 to 2022, increasing slightly to 225 decares in 2023 (Table 1). This stability can be attributed to the persistence of family farming, the use of traditional agricultural knowledge to meet local consumption needs, and limited crop diversity (Kadakoğlu & Karlı, 2022). Furthermore, climate data from TSMS (2025) suggest that these provinces experience fewer extreme weather events, making them more suitable for continued faba bean cultivation. In this

context, the continued presence of small-scale producers presents an essential opportunity for preserving traditional crops, such as faba beans, at the regional level.

Table 1. Faba Bean Cultivation Areas in Türkiye (da)

Provinces	Years					
	2018	2019	2020	2021	2022	2023
Çanakkale	6720	6285	5958	5264	4843	4449
Balıkesir	3476	3458	3395	2830	3076	2835
Kütahya	3050	3020	2805	2310	2266	2227
Bursa	2640	2255	2168	2338	1760	1660
İzmir	1468	1268	454	470	511	1501
Manisa	2360	1740	1790	1620	1502	1320
Zonguldak	1422	1420	1395	1215	1170	1175
Muğla	908	959	1042	1144	1072	1025
Bartın	830	830	840	835	845	790
Tokat	200	200	200	200	200	225
Other	2220	1686	993	782	395	347
Total	25294	23121	21040	19008	17640	17554

(TURKSTAT, 2025)

In contrast, provinces categorized as “Other” experienced a dramatic 84% reduction in faba bean cultivation area—from 2,220 decares in 2018 to only 347 decares in 2023 (Table 1). This decline illustrates the challenges faced in regions where small-scale farming is under-supported, marketing opportunities are limited, and government incentives are unevenly distributed. Yıldız and Sel (2023) argue that rational planning and crop-specific support programs could significantly increase pulse production in Türkiye and meet national demand through domestic production, as demonstrated by their mathematical modeling studies. FAO (2020) also emphasizes that improving water use efficiency and climate adaptation are key priorities for sustainable agricultural production. In conclusion, faba bean production in Türkiye is shrinking both in terms of cultivation area and the number of producers. This trend necessitates a strategic reassessment of the crop’s role in national production systems and a deeper analysis of the underlying factors driving the shift toward alternative crops (Bozoğlu et al., 2014; Önder & Ceyhan, 2011).

3. FABA BEAN PRODUCTION IN TÜRKIYE

Total faba bean production in Türkiye was recorded at 5,903 tons in 2018, but it has since exhibited a consistent downward trend. By 2021, production had declined to 4,426 tons, marking an approximate 25% decrease over four years. Notably, while this decline continued in 2022 with a production level of 4,234 tons, the trend reversed slightly in 2023, with production increasing to 4,268 tons (Table 2). Although this increase remains modest, it is considered significant in terms of slowing the downward trajectory. The fluctuations in production are directly related to reductions in cultivated area and reflect the influence of multiple factors, including climatic conditions, input costs, agricultural support policies, and marketing opportunities (Kadakoğlu & Karlı, 2022; FAO, 2020).

Throughout the examined period, Çanakkale consistently held the highest faba bean production levels in Türkiye. However, production in this province decreased from 1,858 tons in 2018 to 1,304 tons in 2023, representing a 30% decline (Table 2). Çanakkale has long been a leading region in terms of both cultivated area and yield, but the production decline is attributed to

a combination of reduced cultivated area, climate change, and shifting producer preferences (IPCC, 2022; Önder & Ceyhan, 2011). This situation indicates that even in highly productive areas, the sustainability of production is under threat. To counter this loss, the implementation of region-specific support programs and yield-enhancing practices is necessary.

Balıkesir, Kütahya, and Manisa are also significant faba bean production centers following Çanakkale. In Balıkesir, production fell from 799 tons in 2018 to 649 tons in 2023, a decline of approximately 19%. In Kütahya, production decreased from 665 tons to 469 tons, representing a 29% loss. In Manisa, the drop was even more pronounced—from 337 tons in 2018 to 187 tons in 2023, equating to a 44% reduction (Table 2). These decreases reflect both shrinking cultivation areas and declining yields (Bozoğlu, Ceyhan & Karaköy, 2014). The case of Manisa, in particular, highlights the role of irrigation capacity, climatic variability, and rising input costs in contributing to production declines (Ceyhan, 2012).

In contrast, some provinces displayed either production stability or limited increases. For instance, in Muğla, production rose from 242 tons in 2018 to 366 tons in 2023, representing a 51% increase. Similarly, in Zonguldak, production increased from 145 tons to 206 tons, while in Bartın, production levels remained relatively stable throughout the years (Table 2). These positive trends can be attributed to favorable local consumption patterns, farmer experience, and relatively suitable climatic conditions (TSMS, 2025). Furthermore, the continued activity of small family farms and the market value of faba beans in local markets help sustain this stability. Although overall production in Tokat remained low, it nearly doubled from 28 tons to 56 tons, demonstrating that regions with previously low output still hold unexploited agricultural productivity potential (Yıldız & Sel, 2023).

Table 2. Faba Bean Production in Türkiye (tons)

Provinces	Years					
	2018	2019	2020	2021	2022	2023
Çanakkale	1858	1809	1724	1531	1432	1304
Balıkesir	799	792	777	626	695	649
Kütahya	665	657	615	464	456	469
Muğla	242	275	355	332	346	366
Zonguldak	145	145	163	140	205	206
Bartın	192	192	195	197	210	191
Manisa	337	245	247	228	209	187
Tokat	28	28	50	50	50	56
Hatay	46	11	14	17	15	17
Karabük	8	13	17	16	15	15
Other	1583	1317	845	825	601	808
Total	5903	5484	5002	4426	4234	4268

(TURKSTAT, 2025)

Provinces classified under the “Other” category experienced noticeable fluctuations in production. While production was 1,583 tons in 2018, it fell to 601 tons in 2022, only to rise again to 808 tons in 2023 (Table 2). This trend suggests that production has not been completely abandoned in these provinces, and under favorable conditions, a return to cultivation is possible. Bozoğlu et al. (2014) noted that unstable state policies in such smaller production areas can undermine farmer confidence, leading to the temporary abandonment of production. International

organizations such as FAO (2020) and IPCC (2022) emphasize that without structural solutions, such as climate adaptation and efficient water management, these fluctuations are likely to persist. The approximately 27% reduction in national faba bean production over the past five years underscores the need to reassess the crop's strategic role within Türkiye's agricultural production systems (Kadakoğlu & Karlı, 2022). Regionalized and crop-specific agricultural policies are crucial for ensuring sustainable production.

4. FABA BEAN YIELD IN TÜRKIYE

In Türkiye, the average faba bean yield was recorded at 233 kg per decare in 2018 and increased slightly to 243 kg da^{-1} by 2023 (Table 3). These figures indicate a modest yield improvement over the six years. However, the 4.3% increase has not been sufficient to compensate for the overall decline in production. Factors limiting yield growth include the use of underdeveloped seed varieties, limited access to essential agricultural inputs such as fertilizers and irrigation, and a general lack of technical knowledge (Kadakoğlu & Karlı, 2022; Önder & Ceyhan, 2011). In addition, drought, heat stress, and irregular rainfall patterns—primarily driven by climate change—have been significant constraints on productivity (IPCC, 2022; TSMS, 2025).

At the provincial level, Mersin had the highest faba bean yield in Türkiye in 2023, reaching 538 kg da^{-1}. This figure is nearly twice the national average. Yield levels in Mersin have remained consistently high over the years, generally around 500 kg da^{-1}, with only a slight dip observed in 2020. This stability can be attributed to favorable agroclimatic conditions and the application of more advanced production techniques. Muğla has also demonstrated a rising yield trend, increasing from 267 kg da^{-1} in 2018 to 357 kg da^{-1} in 2023—an improvement of approximately 34% (Table 3). This increase reflects the positive outcomes of expanding technical farming practices, particularly in regions dominated by small-scale producers (Bozoğlu, Ceyhan & Karaköy, 2014).

In contrast, provinces such as Tokat, Hatay, and Kütahya have recorded yields well below the national average. In Tokat, yields remained around 140 kg da^{-1} in 2018–2019 and rose to 250 kg da^{-1} from 2020 onward, though this increase remains limited. In Hatay, yield improved from 159 kg da^{-1} in 2018 to 221 kg da in 2023, a 39% increase, yet still below the national average (Table 3). Low yields in these regions are associated with limited agricultural training, continued reliance on traditional farming practices, low input usage, and inadequate marketing infrastructure (Ceyhan, 2012). Furthermore, the limited availability of irrigation and the low priority given to faba bean within local cropping systems reduce overall investment in the crop.

Table 3. Faba Bean Yield in Türkiye (kg da^{-1})

Provinces	Years					
	2018	2019	2020	2021	2022	2023
Mersin	511	511	467	500	500	538
İzmir	277	282	271	274	286	258
Muğla	267	287	341	290	323	357
Çanakkale	276	288	289	291	296	293
Tokat	140	140	250	250	250	249
Bartın	231	231	232	236	249	242
Bursa	235	235	237	234	235	236
Balıkesir	230	229	229	221	226	229
Hatay	159	157	175	207	200	221
Kütahya	218	218	219	201	201	211
Mean of Türkiye	233	237	238	233	240	243

(TURKSTAT, 2025)

Provinces such as Bursa, Balıkesir, Kütahya, and Bartın have shown little to no change in faba bean yield over the years. For example, in Bursa, yields remained stable at approximately 235–236 kg da^{-1} over the six years, while in Balıkesir, yields consistently hovered around 230 kg da^{-1} (Table 3). This stagnation is attributed to the lack of widespread adoption of innovative practices and the continuation of conventional techniques. Kadakoğlu and Karlı (2022) emphasized the need for region-specific training, input subsidies, and increased R&D investments to improve legume yields in Türkiye. Yıldız and Sel (2023) supported this view with mathematical models, demonstrating that agricultural planning can directly contribute to yield increases. In this context, expanding technology transfer and agricultural advisory services in stagnant provinces is crucial for achieving sustainable production.

5. CONCLUSION AND EVALUATION

Based on the data from the past five years, it is evident that faba bean cultivation in Türkiye has undergone a significant contraction in terms of both cultivated area and production volume. The total cultivated area, which stood at 25,294 decares in 2018, declined to 17,554 decares by 2023. During the same period, total production dropped from 5,903 tons to 4,268 tons. This over 30% decline is linked not only to shifting farmer preferences but also to multiple structural factors, including rising production costs, inadequate support policies, climate-related risks, and marketing challenges. The findings of this study indicate that faba bean cultivation, which holds a vital place in traditional and local production systems, faces a growing risk of marginalization in Türkiye.

In terms of productivity, a limited increase has been observed at the national level. Yield rose from 233 kg da^{-1} in 2018 to 243 kg da^{-1} in 2023. However, this 4.3% increase has not been sufficient to offset the declines in cultivated area and production. While notable yield improvements were recorded in provinces such as Mersin and Muğla, yields in regions like Tokat, Hatay, and Kütahya remained below the national average. These yield disparities are directly related to climatic conditions, infrastructure limitations, the level of farmers' knowledge, and the agricultural technologies employed. This highlights that agrarian productivity is shaped not only by physical inputs but also by technical efficiency and informational capacity.

Regional analyses indicate that key faba bean-producing provinces have maintained their significance, despite production and yields declining in these areas. The reductions observed in leading production centers such as Çanakkale, Balıkesir, and Kütahya reflect the broader national trend. Conversely, provinces like Muğla, Tokat, and Zonguldak exhibited either stability or slight increases in both production and yield. These exceptions indicate that small-scale producers still hold considerable production potential and that faba bean cultivation can remain sustainable under favorable conditions.

To ensure the sustainability of faba bean cultivation in Türkiye, both macro-level agricultural policies and micro-level producer support mechanisms need to be restructured. Crop-specific support models, regional agricultural planning, yield-enhancing R&D efforts, and farmer training programs are critically important in this context. Furthermore, the promotion of climate-resilient production systems and the increased use of drought-tolerant local varieties carry strategic importance for mitigating future risks.

In conclusion, this study has quantitatively assessed the recent changes in faba bean cultivation area, production, and yield in Türkiye over the past five years and has explained the underlying drivers of these changes. The findings offer valuable insights not only for faba bean cultivation but also for the broader sustainability of pulse production systems in Türkiye. Future

research should aim to develop these findings further and inform the development of region-specific strategies.

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THE COURSE OF COWPEA CULTIVATION IN TÜRKIYE: AREA, PRODUCTION, AND YIELD

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ABSTRACT
Cowpea is a legume species that holds a significant place in sustainable agricultural systems due to its resilience to hot climates, ability to fix atmospheric nitrogen, and high protein content. This study aims to evaluate the trends in cowpea cultivation in Türkiye between 2018 and 2023 by analyzing changes in cultivated area, production volume, and yield levels. Based on data from the Turkish Statistical Institute (TURKSTAT, 2025), it was found that the total cultivation area in Türkiye decreased from 13,553 hectares in 2018 to 11,293 hectares in 2023, with production volume declining until 2022. However, a partial recovery was observed in 2023, driven by significant yield increases in certain provinces such as Uşak and Hatay. While Manisa province consistently had the largest share of production and cultivated area throughout the six years, its yield levels remained low, at around 80 kg da^{-1}. In contrast, provinces like Hatay and Çanakkale recorded yields above 200 kg da^{-1} in 2023, indicating that regional differences in climate conditions and agronomic practices are critical determinants of productivity. The analysis, supported by the IPCC (2022), FAO (2020, 2021), and other relevant literature, reveals that climate change, water scarcity, inadequate agricultural infrastructure, and market limitations are significant threats to cowpea production in Türkiye. The findings suggest that enhancing the sustainability of cowpea cultivation requires the implementation of climate-adaptive policies, localized agricultural support mechanisms, and the dissemination of modern production technologies. If such strategies are not effectively pursued, the future of cowpea production, despite its ecological and nutritional importance, may remain at risk within Türkiye's broader agri-food systems.
Keywords: Cowpea production, yield trends, cultivated area, climate change, sustainable agriculture

1. INTRODUCTION

Legumes are considered one of the cornerstones of sustainable agriculture due to their agroecological functionality, high protein content, and nitrogen fixation capabilities within agricultural production systems (FAO, 2021). Among this group, cowpea (*Vigna sinensis* (L.) Savi) stands out as a species well adapted to warm climates, suitable for low-input systems, and possessing versatile usage options. Especially when consumed as fresh green cowpea (vegetable form) and used as a pulse in its dry seed form, cowpea becomes a strategic crop in terms of both food security and rural income (Harmankaya et al., 2016; Jou-Nteufa & Ceyhan, 2024).

However, cowpea cultivation in Türkiye has shown a notable fluctuation in recent years in terms of both sown area and total production. According to TÜİK (2025) data, the total sown area, which was 13,553 decares in 2018, decreased to 11,293 decares by 2023. Similarly, total production, which was 1,443 tons in 2018, dropped to 1,161 tons in 2022 but rose again to 1,432 tons in 2023, indicating a fluctuating trend. These figures suggest that cowpea production in Türkiye is struggling to maintain its sustainability due to environmental, economic, and structural factors.

The effects of climate change on agricultural production have become more pronounced for species sensitive to environmental stressors, such as cowpea. According to the IPCC (2022) report, increasing temperatures, declining precipitation levels, and more frequent extreme weather events are putting agricultural production under pressure, particularly in the Mediterranean basin. The observed decrease in cowpea area and production in the Aegean and Inner Western Anatolia regions—key cultivation zones in Türkiye—clearly reflects the field-level impacts of climatic variability. The declines in traditional production centers such as Manisa, İzmir, and Uşak further indicate a shift in farmers' perception of climate-based risks.

In terms of yield, the national average yield for cowpea in Türkiye reached 127 kg da^{-1} in 2023, representing a noticeable increase compared to previous years (TURKSTAT, 2025). This increase is attributed to high yield values recorded in certain provinces like Hatay and Uşak. While the FAO (2020) emphasizes the need to improve productivity in agriculture in response to water scarcity, the FAO (2021) recommends implementing region-specific agronomic strategies better to harness the potential of legumes in sustainable production systems. Nevertheless, the persistently low productivity in high-sown-area provinces such as Manisa highlights a quantitative and qualitative imbalance in production.

Agricultural productivity depends not only on biophysical conditions but also on access to agricultural knowledge, support policies, marketing opportunities, and infrastructure adequacy. Parfitt et al. (2010) note that post-harvest losses are widespread in small-scale production systems, thereby reducing overall production capacity. In Türkiye, many farmers still rely on traditional practices and face limitations in accessing essential inputs such as modern irrigation systems, high-quality seed, and extension services. This situation poses a threat to the sustainability of production, particularly in regions with low yields.

In conclusion, the current status of cowpea cultivation in Türkiye is shaped by multifaceted factors such as the impacts of climate change, deficiencies in agricultural infrastructure, and low economic returns. Wheeler and von Braun (2013) argue that vulnerable food systems can only be strengthened through systematic policy transformations in response to climate change. In this context, restructuring and expanding cowpea cultivation in Türkiye will require region-based support policies, climate-adaptive production strategies, and strengthened market integration mechanisms.

2. COWPEA CULTIVATION IN TÜRKIYE

In Türkiye, cowpea cultivation areas have declined from 13,553 decares in 2018 to 11,293 decares by 2023, indicating a decrease of approximately 16.6% (Table 1). This reduction can be attributed primarily to environmental factors such as drought, diminishing water resources, and the vulnerability of agricultural production to climate change. The IPCC (2022) report highlights that rising temperatures and irregular precipitation patterns hurt crop productivity and planting decisions, particularly for low-input crops. The overall downward trend in Türkiye reflects local manifestations of these global shifts.

Manisa province has consistently led cowpea cultivation throughout the years; however, its sown area has decreased from 7,694 decares in 2018 to 6,875 decares in 2023 (Table 1). The FAO (2021) emphasizes the role of legumes in sustainable agricultural systems, stressing their strategic importance due to their ability to grow under arid conditions with minimal inputs. Nevertheless, the decline even in a key production center like Manisa suggests that producers may be shifting toward more secure crops or that adequate agricultural support is lacking. Moreover, water stress plays a crucial role in influencing production decisions (FAO, 2020).

Systematic declines are particularly striking in Aegean provinces such as Muğla, Uşak, İzmir, and Aydın. In İzmir, the dramatic 69% decrease indicates both climatic pressure and a structural transformation in agriculture (Table 1). Lobell and Gourdji (2012) report that rising temperatures shorten the photosynthetic period, leading to yield losses; this issue becomes particularly critical for summer crops during the flowering stage, causing stress and reduced yields. Such biophysical stresses drive producers away from sensitive crops, such as cowpea.

In provinces such as Balıkesir, Denizli, Çanakkale, Isparta, and Kütahya, cowpea production volumes remain relatively low, with only limited increases (Table 1). Parfitt et al. (2010) note that post-harvest losses are substantial in small-scale agricultural systems, diminishing producer motivation. In crops like cowpea, which have a short shelf life and are relatively complex to market, these losses negatively impact economic sustainability. The stagnation in these provinces may also be attributed to infrastructural deficiencies and limited market access.

Table 1. Cowpea Cultivation Areas in Türkiye (da)

Provinces	Years					
	2018	2019	2020	2021	2022	2023
Manisa	7694	7240	7320	6970	6975	6875
Uşak	2286	2290	2350	2150	1800	1820
Muğla	1635	1621	1557	1455	1182	1177
Balıkesir	452	400	456	392	449	448
Denizli	389	610	517	488	285	265
Çanakkale	80	55	228	247	240	228
Isparta	350	231	321	289	239	217
İzmir	424	382	223	242	168	132
Aydın	100	90	105	115	105	78
Kütahya	50	70	70	70	60	40
Other	93	95	80	27	18	13
Total	13553	13084	13227	12445	11521	11293

(TURKSTAT, 2025)

The contraction in cowpea cultivation areas across Türkiye is not solely a consequence of climatic conditions but also reflects governance gaps, insufficient incentives, and a decline in agricultural awareness. Wheeler and von Braun (2013) emphasize that climate change exerts multifaceted effects on food security, and the solution lies not only in boosting production but also in adopting systematic adaptation policies. In Türkiye, agroecologically based planning, water management reforms, and farmer education programs are urgently needed to protect and develop native, environmentally adapted crops.

3. COWPEA PRODUCTION IN TÜRKIYE

In Türkiye, cowpea production decreased from 1,443 tons in 2018 to 1,161 tons in 2022, before rising again to 1,432 tons in 2023 (Table 2). This fluctuating trend reveals the vulnerability of both climatic conditions and production decisions. According to the IPCC (2022) report, climate change has complex and region-specific effects on agricultural production; in particular, reduced precipitation and rising temperatures in semi-arid regions constrain productivity. The trends observed in Türkiye's cowpea production can be considered local agricultural reflections of this global climatic pressure.

Although Manisa has maintained its leadership in production, output dropped from 718 tons in 2018 to 551 tons in 2023 (Table 2). This decrease is likely due to both the reduction in cultivated areas and the increasing impact of water stress. The FAO (2020) emphasizes that improving water-use efficiency is essential for sustaining agricultural production in water-scarce regions. In areas like Manisa, where irrigation-based agriculture is prevalent, updating water management policies can have a direct impact not only on crop productivity but also on total production volumes.

In Uşak, an exceptional increase in production was recorded in 2023, reaching 455 tons. This surge may result from both expanded cultivation areas and favorable climatic conditions during that year (Table 2). The FAO (2021) highlights the significance of legumes in sustainable food systems and notes their ability to demonstrate high environmental adaptability even under low-input systems. The observed production increase in Uşak suggests that cowpea cultivation can be enhanced under suitable agroclimatic conditions and with proper guidance from farmers. A similar recovery trend seen in Muğla may also indicate a climate-related, temporary improvement.

Table 2. Cowpea Production in Türkiye (tons)

Provinces	Years					
	2018	2019	2020	2021	2022	2023
Manisa	718	685	581	556	561	551
Uşak	232	232	229	240	180	455
Muğla	249	233	238	230	195	215
Balıkesir	79	68	89	71	79	79
Çanakkale	14	12	51	57	54	52
Denizli	39	61	52	49	29	27
İzmir	59	54	30	35	26	22
Isparta	28	20	28	25	21	19
Aydın	6	5	6	7	7	5
Kütahya	5	7	7	7	6	4
Other	14	15	13	4	3	3
Total	1443	1392	1324	1281	1161	1432

(TURKSTAT, 2025)

In provinces such as İzmir, Denizli, Isparta, Aydın, and Kütahya, production levels are pretty low and have shown a declining trend over the years. Notably, production in İzmir dropped significantly from 59 tons in 2018 to just 22 tons in 2023, revealing a substantial decrease in the region's production capacity (Table 2). Parfitt, Barthel, and Macnaughton (2010) point out that post-harvest losses are common in small-scale agricultural operations and that infrastructure deficiencies lower producers' motivation. Furthermore, Wheeler and von Braun (2013) stress that the impacts of climate change on agriculture and food security must be addressed not only through biophysical perspectives but also by considering socioeconomic dimensions. The production declines in Türkiye's small-scale producer provinces highlight the urgent need for structural reforms.

4. COWPEA YIELD IN TÜRKIYE

Throughout Türkiye, cowpea yield remained stable at 106 kg da^{-1} in 2018 and 2019, declined slightly to around 101 kg da^{-1} between 2020 and 2022, and then rose significantly to 127 kg da^{-1} in 2023. This increase was mainly driven by high yields recorded in Hatay and Uşak provinces in 2023, with each reaching 250 kg da^{-1} (Table 3). The rise in the national average may be attributed to relatively favorable climatic conditions or the introduction of more productive varieties and improved cultivation techniques. Moreover, this upward trend indicates that local adaptation is possible despite the impacts of climate change (IPCC, 2022). Hatay became the leading province in terms of cowpea yield in 2023, reaching 250 kg da^{-1} and demonstrating a consistent upward trend over the years (Table 3). According to the FAO (2021), legumes have high yield potential, especially under well-managed climatic and soil conditions. Uşak also achieved a remarkable leap, increasing its yield from 100 kg da^{-1} to 250 kg da^{-1} in 2023. This improvement could be attributed to the reassessment of cultivated lands, enhancements in irrigation conditions, or improved access to agricultural knowledge for farmers. Likewise, Çanakkale gradually increased its yield from 175 kg da^{-1} in 2018 to 228 kg da^{-1} in 2023. In Manisa, Türkiye's leading province in total production, the yield remained unchanged at 80 kg da^{-1} between 2018 and 2023 (Table 3). This indicates low agricultural productivity despite the large cultivation area. The FAO (2020) notes that water scarcity and low soil fertility are key limiting factors in such yield stagnation. Similarly, provinces like Isparta and Kütahya have also shown static yield levels for years (Isparta: 88 kg da^{-1}; Kütahya: 100 kg da^{-1}), which may be linked to outdated agricultural practices or agroclimatic conditions that do not permit higher yields (Table 3).

Table 3. Cowpea Yield in Türkiye (kg da^{-1})

Provinces	Years					
	2018	2019	2020	2021	2022	2023
Hatay	164	173	171	200	200	250
Uşak	101	101	102	112	100	250
Çanakkale	175	218	224	231	225	228
Muğla	152	144	153	158	165	183
Balıkesir	175	170	195	181	176	176
İzmir	139	141	135	145	155	167
Denizli	100	100	101	100	102	102
Kütahya	100	100	100	100	100	100
Manisa	93	95	79	80	80	80
Other	80	87	87	87	88	88
Mean of Türkiye	106	106	101	103	101	127

(TURKSTAT, 2025)

Yield data reveal that cowpea farming in Türkiye holds considerable potential but exhibits significant regional disparities in productivity. While some provinces have achieved remarkably high yields of 250 kg da^{-1}, others remain at 80–100 kg da^{-1} levels (Table 3). These differences are closely related not only to climatic conditions but also to agricultural support policies, irrigation infrastructure, seed quality, and farmer education (Wheeler & von Braun, 2013). Therefore, balancing production efficiency nationwide is achievable through region-specific support programs, local adaptation initiatives, and strengthened extension services in low-yielding areas.

5. CONCLUSION AND EVALUATION

Cowpea cultivation in Türkiye between 2018 and 2023 exhibited a fluctuating and vulnerable trend in terms of cultivated area, production, and yield. According to TÜİK (2025) data, the total cultivated area declined by 16.6%, and production continued to decrease until 2022; however, a notable increase was observed in 2023. This indicates that cowpea production is unstable and highly sensitive to environmental and structural factors. It is evident that cowpea cultivation in Türkiye remains concentrated in limited regions and generally holds a marginal position within the agricultural sector.

Climate change remains a significant factor affecting cowpea production in Türkiye. As highlighted by the IPCC (2022) and FAO (2020), increasing temperatures, decreasing rainfall, and water stress threaten agricultural productivity, particularly in semi-arid regions. Even in leading production provinces like Manisa, yields have remained low at around 80 kg da^{-1}. In contrast, provinces such as Hatay, Uşak, and Çanakkale have exceeded 200 kg da^{-1} due to favorable climate conditions and modern practices. This demonstrates the importance of climate-adaptive strategies and micro-regional approaches.

Low productivity and shrinking cultivation areas in cowpea farming raise questions about the effectiveness of current agricultural support policies. Especially for small-scale producers, challenges in accessing modern irrigation systems, quality seed, and extension services limit yield improvements (Parfitt et al., 2010). Additionally, deficiencies in rural infrastructure and weak marketing channels reduce farmer income, leading to a decline in cowpea cultivation. In this context, producer support must extend beyond input subsidies to include knowledge transfer and logistical improvements.

As stated by FAO (2021), legume species such as cowpea contribute to soil health through biological nitrogen fixation and support the development of environmentally friendly agricultural systems. Nevertheless, trends threatening the sustainability of cowpea production in Türkiye may, in the long term, narrow agricultural diversity and weaken legume-based food security. Therefore, breeding climate-resilient varieties, disseminating appropriate agricultural technologies, and enhancing farmer training are of critical importance.

Revitalizing cowpea cultivation in Türkiye holds strategic significance not only for agricultural production but also for rural development, biodiversity, and climate adaptation policies. As Wheeler and von Braun (2013) suggested, resilient food systems in the face of climate vulnerability require integrated policy mechanisms. In this regard, the development of region-specific support schemes, planning based on water-use efficiency, and strengthening farmers' market integration should be prioritized. Otherwise, the decline of strategic crops like cowpea will continue to negatively impact not only the agricultural sector but also the sustainability of food systems.

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MICROSTRIP ANTENNA DESIGN FOR BIOMEDICAL APPLICATIONS

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Abstract
The advancement of wireless communication in the biomedical sector has led to the development of specialized antennas for medical applications. Microstrip antennas are widely used due to their compact size, low cost, and ease of integration with wearable and implantable medical devices. This paper presents a detailed analysis of microstrip antenna design for biomedical applications, discussing key design parameters, material selection, performance characteristics, and real-world applications. The study also explores the impact of human tissue on antenna performance and provides insights into optimizing antenna design for enhanced efficiency in medical diagnostics and treatment.
Keywords: Antenna, Biomedical, ISM, Microstrip, SAR, UWB, wearable.

Introduction

Biomedical applications have increasingly adopted wireless communication technologies for non-invasive diagnostics, monitoring, and treatment. Among the various antenna types, microstrip antennas offer unique advantages such as biocompatibility, flexibility, and minimal interference with human tissues. This paper explores the significance of microstrip antennas in biomedical applications, the challenges involved in designing these antennas for different medical scenarios, and the solutions that improve their performance.

Literature Survey

Several studies have explored microstrip antennas for biomedical applications, focusing on aspects such as impedance matching, miniaturization, and Specific Absorption Rate (SAR) reduction. Research indicates that substrates with high permittivity, such as Rogers RT/Duroid and flexible polymers, enhance antenna performance. Previous works have also demonstrated that frequency bands such as ISM (Industrial, Scientific, and Medical) and UWB (Ultra-Wideband) are suitable for biomedical devices. The literature highlights advancements in wearable antennas for continuous health monitoring and implantable antennas for deep-tissue communication.

Design

The antenna design with length width height and feeding point is shown in figure 1 for the biomedical application beneath skin. The simulated result is displayed in figure 2.

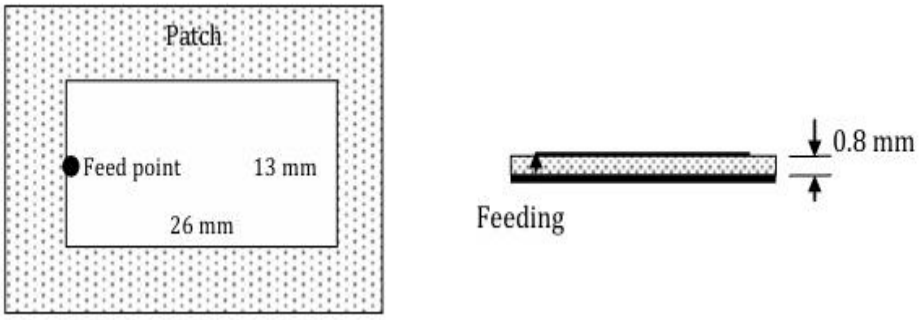

Figure 1.Designed Patch antenna at 2.5 GHz

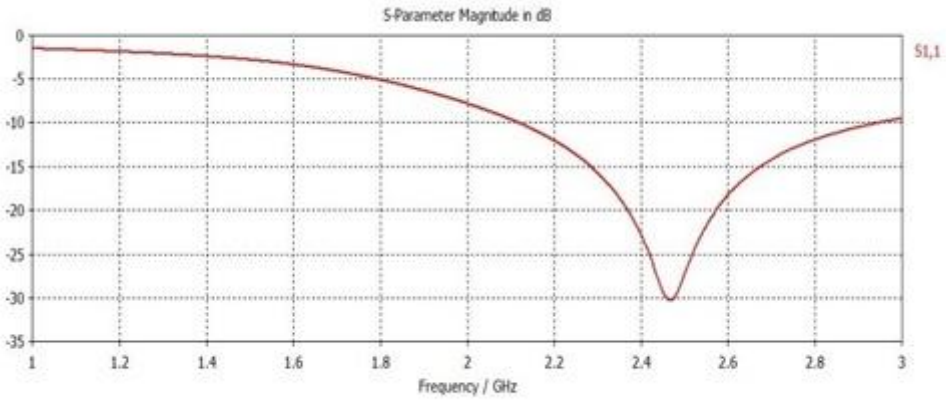

Figure 2.Designed Simulated results of antenna at 2.5 GHz

Methodology

The design of microstrip antennas for biomedical applications involves several key steps:

1. **Material Selection:** Choosing a biocompatible substrate with suitable dielectric properties.
2. **Antenna Structure Design:** Optimizing dimensions for miniaturization while ensuring efficient radiation characteristics.
3. **Simulation and Testing:** Using software tools like CST Microwave Studio and HFSS to evaluate antenna performance under real-world conditions.
4. **Performance Metrics:** Analyzing parameters such as return loss, gain, bandwidth, and SAR to ensure compliance with biomedical safety standards.
5. **Fabrication and Experimental Validation:** Prototyping antennas using flexible and implantable materials and testing their performance on phantoms or animal models.

Results and Discussion

Table 1: Electromagnetic prosperities of human body tissue at 2.45 GHz

Parameters	Skin	Fat	Muscle
Permittivity, ε_r	37.951	5.2650	51.99
Conductivity , σ S/m	1.4775	0.1056	1.7540
Loss Tangent, δ	0.2802	0.1390	0.2399

Simulation results indicate that microstrip antennas designed with flexible and low-loss substrates exhibit improved efficiency and reduced SAR. Experimental validation shows that the antennas operate efficiently in predefined frequency bands suitable for biomedical applications. The impact of human tissue on impedance matching and gain reduction is analyzed, and techniques such as artificial ground planes and metamaterials are proposed to enhance performance.

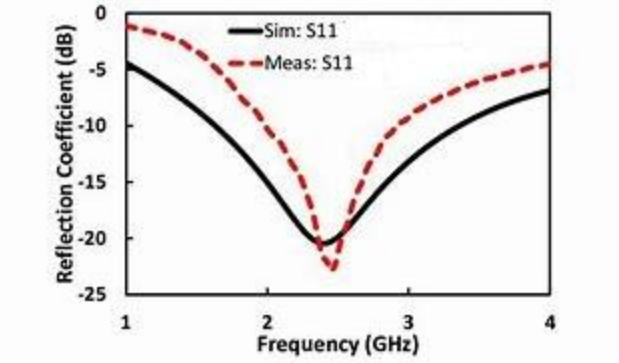

Figure 3. Simulated and Measured results of antenna comparison at 2.5 GHz

Conclusion

Microstrip antennas play a crucial role in biomedical applications by enabling wireless communication for diagnostics and treatment. The study demonstrates that proper material selection, structure optimization, and performance validation are essential for designing effective biomedical antennas. Future research can focus on developing reconfigurable antennas with adaptive frequency tuning for enhanced versatility in medical applications.

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A REVIEW ON THE TREATMENT OF LAUNDRY WASTEWATER USING CONVENTIONAL AND ADVANCED TREATMENT METHODS

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ABSTRACT
Laundry wastewater is a major source of environmental pollution due to its complex and variable composition. It typically contains harmful substances such as detergents, surfactants, phosphates, oils, suspended solids, and micro-pollutants, which are released from cleaning agents and fabrics during the washing process. If discharged into the environment without adequate treatment, these contaminants can lead to serious ecological problems. They may cause oxygen depletion in water bodies, disturb aquatic life, reduce biodiversity, and contribute to the formation of harmful algal blooms, ultimately threatening the health of aquatic ecosystems and nearby communities. In order to protect water resources and preserve the environment, various treatment methods are implemented to reduce and remove detergents from laundry wastewater .In this study, the treatment of laundry wastewater using various methods such as coagulation-flocculation, biological treatment, sand filtration, adsorption, electrocoagulation, ozonation, membrane bioreactor, ultrafiltration, electrooxidation, peroxicoagulation, Fenton, and some of their combinations was examined. The effectiveness of the applied treatment methods in treating laundry wastewater has been demonstrated. In addition, the study highlights that the careful selection and application of appropriate treatment technologies play a vital role in minimizing environmental damage, ensuring regulatory compliance, and promoting sustainable water resource management. This study also showed the effectiveness of various innovative technologies and provided comparative insights through literature-based data and performance outcomes.
Key words: Laundry wastewater treatment, detergent, advanced treatment, water pollution

1. Introduction

Wastewater is a complex mixture that can contain high levels of organic, inorganic, and microbiological pollutants, resulting from domestic, industrial, and agricultural activities. Discharging these waters into receiving environments without adequate treatment can negatively affect water quality, disrupt ecosystem functioning, pose a threat to public health, and lead to economic losses. Recently developed advanced treatment technologies effectively remove both persistent organic pollutants and heavy metals. Wastewater management is of critical importance not only for ensuring environmental sustainability but also for the protection of the water cycle and the reuse of resources. In this context, the development and integration of innovative treatment methods are considered a fundamental requirement for the success of sustainable development policies.

Laundry wastewater contains a variety of pollutants, including detergents, soap powders, various chemicals, heavy metals, mineral oils, dyes, and suspended solids. (Cüce. H 2023). The physical and chemical properties of laundry wastewater can vary significantly depending on several factors, including the type of textile products being washed, the volume of water used, and the composition of the cleaning agents employed.

Detergents are complex chemical compounds used for cleaning various materials, such as textile surfaces, kitchen utensils, and hard surfaces. The formulation of these products typically includes various additives, such as surfactants, builders, enzymes, bleaching agents, fragrance components, and colorants. (Khan 2022). Detergents are classified into four main groups based on their chemical structure: anionic, cationic, non-ionic, and amphoteric surfactants. Each group exhibits distinct physicochemical properties, depending on the nature of the interactions at the surface and their specific areas of application. (Irshad N. Shaikh 2024).

Laundry wastewater contains high levels of toxic compounds, and if discharged into receiving water bodies without proper treatment, it can lead to water pollution and eutrophication. This disrupts aquatic ecosystems, degrades water quality, and threatens biodiversity. Therefore, various treatment methods are employed to remove detergents from laundry wastewater in order to minimize environmental impacts and preserve ecological balance. (Procházková. M 2022).

Laundry wastewater contains toxic components derived from detergents (such as phosphates, LAS, SLS, etc.), and if not properly treated, it can lead to water pollution, eutrophication, and a loss of biodiversity. These components alter the physical and chemical properties of water, increase oxygen consumption, and threaten the survival of aquatic organisms. Phosphates cause algal blooms, which reduce oxygen levels, while surfactants like LAS can affect fish gills and eyes. High detergent concentrations have toxic effects on fish and bacteria, limiting metabolic activities. Additionally, they reduce the bioremediation capacity of fungi and hinder biomass production. Aquatic plants experience chlorophyll loss, growth retardation, and a decrease in photosynthesis. In soil, detergents raise pH and salinity, reducing fertility. Irrigation with contaminated water adversely affects plant health and germination rates. In the long term, detergent pollution threatens the balance of water and soil ecosystems. Therefore, the treatment of detergent-containing wastewater is of critical environmental importance (Pandey. P 2010); (Rejeki S 2013); (Anwar 2011); (HAMEED.A 2005); (Jovanić. B. R 2010).

2. Laundry Wastewater Treatment Methods

In order to protect water resources and preserve the environment, various treatment methods are implemented to reduce and remove detergents from laundry wastewater. These methods include adsorption, membrane bioreactors, peroxicoagulation, electrocoagulation/electroflotation,

biological processes, advanced oxidation processes (AOPs), as well as combinations of these techniques, all of which have been utilized effectively in the treatment of laundry wastewater (Cüce. H 2023); (Meli´an. E.P 2023); (Josepha. C. G 2021); (MARCHESI. J. R 1991); (Nugroho. F. A 2020). The Foto-Fenton method is an advanced oxidative treatment process that utilizes a combination of Fenton's reagent and UV light to degrade contaminants in wastewater. This method enhances the oxidation of organic pollutants and has been studied for its effectiveness in treating laundry wastewater. In a study on laundry wastewater, the Foto-Fenton method demonstrated impressive removal efficiencies of 92.6% for COD, 96.67% for total phosphorus, and 95.74% for detergent, while generating 16 kg of sludge. In contrast, the biological treatment method, which combines a biofilter and granular activated carbon, showed removal efficiencies of 94.64% for COD, 33% for total phosphorus, and 95.74% for detergent (Meli´an. E.P 2023).

The Ozone Treatment method, an advanced oxidation process (AOP), utilizes ozone (O_3) to break down organic contaminants in wastewater. This process is highly effective in degrading surfactants and detergents due to the strong oxidizing properties of ozone. In laundry wastewater treatment, the Ozone Treatment method has been shown to remove between 70% and 100% of surfactants and detergents, significantly reducing the environmental impact of the effluent. This method also contributes to the reduction of other organic pollutants, making it a valuable option for improving water quality (Josepha. C. G 2021). Electric flocculation is an electrochemical treatment process that uses an electric current to generate flocs, which help in the removal of pollutants from wastewater. This method has shown to be effective in treating laundry wastewater, particularly in removing various contaminants. In the case of liquid detergent laundry wastewater, electric flocculation achieved removal efficiencies of 84% for COD, 93% for LAS (linear alkylbenzene sulfonate), and 96% for turbidity. For powder detergent laundry wastewater, the removal efficiencies were slightly lower, with 80% for COD, 83% for LAS, and 91% for turbidity, indicating the method's effectiveness across different detergent types (Shan Hu. SH 2021).

The Moving Bed Biofilm Reactor (MBBR) method is an advanced biological treatment process that utilizes biofilm-coated carriers suspended in the wastewater to enhance microbial degradation of pollutants. This system provides high treatment efficiency, particularly for organic and surfactant pollutants, due to its large surface area for microbial attachment. In wastewater treatment, the MBBR method demonstrated impressive removal rates, achieving 77%–95% for chemical oxygen demand (COD), 88%–96% for biochemical oxygen demand (BOD), and 91%–99% for total surfactants (including both anionic and nonionic types). Specifically, the removal efficiencies for anionic surfactants ranged from 94.8% to 99.4%, while nonionic surfactants were removed with efficiencies of 94.2% to 99.5%. This highlights the MBBR's effectiveness in treating a broad range of contaminants in wastewater (Bering. S 2020). The integrated treatment process combining Moving Bed Biofilm Reactor (MBBR), UV/O_3, Microfiltration (MF), and Nanofiltration (NF) offers a highly effective approach for treating laundry wastewater. This combination leverages the strengths of biological, chemical, and membrane filtration processes to achieve high pollutant removal efficiencies. In this treatment system, removal efficiencies ranged from 95% to 97% for biochemical oxygen demand (BOD), 90% to 93% for chemical oxygen demand (COD), and 89% to 99% for surfactants. The UV/O_3 pretreatment step significantly reduced total organic carbon (TOC) by 68% and also helped in mitigating membrane fouling. This improvement in fouling control led to a doubling of the microfiltration permeate flux in System B compared to System A. As a result, the treated wastewater from this multi-step process was deemed suitable for reuse in the laundry process, demonstrating its sustainability and efficiency (Mozia. S 2020).

The microbubble flotation method is a highly effective treatment process that utilizes fine microbubbles to enhance the removal of contaminants from wastewater. This technique leverages the buoyancy of microbubbles to trap and float hydrophobic particles, allowing them to be easily separated from the water. In the treatment of laundry wastewater, the microbubble flotation method demonstrated exceptional efficiency, successfully removing over 98% of microplastics and microfibers, as well as over 95% of surfactants. This method is particularly effective in addressing the environmental concerns associated with microplastics and detergents in wastewater, providing a sustainable solution for wastewater treatment in the laundry industry (Zhao. H 2024).

The electrocoagulation process is an electrochemical treatment method that uses electrical currents to generate coagulating agents, which facilitate the removal of pollutants from wastewater. This process is particularly effective in treating complex wastewater, including laundry effluents, by destabilizing and aggregating contaminants into flocs that can be easily separated. In the treatment of laundry wastewater, the electrocoagulation process demonstrated significant removal efficiencies, achieving reductions of 80.76% in chemical oxygen demand (COD), 27.11% in surfactants, 17.66% in total dissolved solids (TDS), and 74.12% in turbidity. These results highlight the method's potential for effectively reducing key contaminants in laundry wastewater, making it a valuable option for improving water quality (Nugroho. F. A 2020).

A study on electroflotocoagulation combined with adsorption for laundry wastewater treatment demonstrated enhanced pollutant removal when these two methods were integrated. At a current density of 80 A/m², the electroflotocoagulation process alone achieved removal rates of 80% for synthetic surfactants, 80% for color, and 85% for turbidity. When an adsorption column was incorporated as a post-treatment step after the electroflotocoagulation reactor, the removal efficiencies improved significantly. Surfactants and color removal rates increased to 95%, while turbidity removal reached 97%. Additionally, this combined treatment process resulted in a 50% reduction in energy consumption, showcasing its efficiency and sustainability in wastewater treatment (Dimoglo. A 2023).

In a study on laundry wastewater treatment using polymeric composites, the amount of adsorbent emerged as the most effective factor for detergent removal, achieving an efficiency of 82%. This highlights the importance of selecting the right adsorbent quantity for effective removal of detergent pollutants. The mixing rate also played a significant role, particularly in the removal of chemical oxygen demand (COD), where it influenced the removal efficiency by 31%. pH was identified as the second most important factor for both detergent and COD removal processes, underscoring its role in optimizing the treatment conditions for enhanced pollutant removal (Veli. S 2021).

The Peroxi-coagulation (PC) process is an advanced treatment method that combines coagulation with the generation of hydroxyl radicals through the use of hydrogen peroxide. In this process, iron anodes and carbon-polytetrafluoroethylene (PTFE) cathodes are employed to facilitate the oxidation and coagulation of contaminants in wastewater. For laundry wastewater treatment, the Peroxi-coagulation process demonstrated significant effectiveness, achieving surfactant and chemical oxygen demand (COD) removal efficiencies ranging from 67% to 95%. This variability in efficiency highlights the process's adaptability and potential for effective treatment of different types of laundry wastewater, providing a viable option for reducing contaminants in the effluent (Nayira. T. Y 2020).

The electro-hybrid ozonation-coagulation (E-HOC) process is an innovative wastewater treatment method that combines the power of electrocoagulation with ozonation to enhance the removal of pollutants. The process leverages electrochemical reactions and ozone to break down

organic contaminants and promote coagulation, effectively targeting a wide range of pollutants. In the treatment of laundry wastewater, the E-HOC process demonstrated excellent performance, achieving removal efficiencies greater than 90% for both surfactants and microplastics. This high efficiency highlights the process's potential in addressing key environmental concerns related to the presence of surfactants and microplastics in wastewater (Luo. J 2022).

Summary information regarding the application examples of these methods reported in the literature is presented in Tables 2 and 3. These tables visually highlight the advantages and disadvantages of the methods, providing important guidance in selecting the appropriate treatment technology.

Table [1] Studies from Literature

Treatment Methods	Wastewater	Efficiency	Year	References
Photo- Fenton	Laundry	COD - 92.6% Total Phosphorus - 96.67% Total Detergent - 95.74% 16 kg sludge	2023	[30]
Biological treatment (biofilter + granular activated carbon)		COD - 94.6% 4 Total Phosphorus - 33% Total Detergent - 95.74%		
Catalytic ozonation using ZnO	Laundry	COD - 89.3% effective for detergent.	2022	[31]
• Electrocoagulation • Ozonation • Advanced Oxidation Processes • Membrane Bioreactors • Ozonation and combined Advanced Oxidation Processes	Laundry	COD - Up to 89% removal with electrocoagulation, up to 93% removal with ozonation. Detergents - Efficiently removed in systems such as Advanced Oxidation Processes and Membrane Bioreactors (exact percentages vary depending on conditions). Pharmaceuticals - More than 90% removal with processes such as ozonation and combined Advanced Oxidation Processes.	2022	[32]
• Precipitation/Coagulation • Granular Activated Carbon Adsorption • Membrane Filtration (UF) • Reverse Osmosis (RO) • Ozone and UV Methods (O3/UV) • Electrooxidation (EO) • Coagulation/Flocculation/UV/H2O2	Laundry	**Sedimentation/Coagulation:** 36% COD and 51% BOD5 removal in organic load, 90% phosphorus removal and pH value decreased from 9.6 to 7.9. Temperature decreased from 62°C to 22°C. **Granular Activated Carbon Adsorption:** COD decreased by 93%, BOD5 decreased by 95%, phosphorus was removed by 90% and pH value decreased from 9.6 to 6.8. **Membrane Filtration (UF):** COD and BOD5 decreased by 55% and 56% respectively, nitrogen was reduced by 99.9% and phosphorus was reduced by 95%. pH decreased from 9.7 to 8.3. **Reverse Osmosis (RO):** COD and BOD5 were removed by 98.9% and 99.2% respectively, nitrogen was removed by 99.9% and phosphorus was removed by 98.5%. pH reduced from 9.7 to 7.6. **Advanced Oxidation (O3/UV):** COD reduced by 29-37%, BOD5 by 26-41%, phosphorus by 30-44%, and nitrogen by 0-42%. Toxicity reduced by 92-96%. **Electrooxidation (EO):** Low reduction in COD and BOD5, but blindness and increased color were observed. Toxicity reduced by 91%. **Coagulation/Flocculation/UV/H2O2:** BOD5 and COD were completely removed, phosphorus by 100%, and toxicity by 100%.	2020	[17]
1. Electrocoagulation–Electroflotation 2. Coagulation, membrane filtration 3. Coagulation-flocculation, sand filter and activated carbon 4. Coagulation, membrane filtration 5. Sand filtration, activated carbon, coagulation 6. Electrocoagulation, adsorption 7. Coagulation/flocculation/sedimentation, membrane 8. Electrocoagulation/Electroflotation 9. Coagulation/flocculation/sedimentation-adsorption	Laundry	95.82–95.87% 98.93% 62.00% 74–82% 63.00% 55–65% 20–75% 68.60% 70.00%	2020	[2]
1. Chemical Precipitation 2. Detoxification 3. Adsorption 4. Chemical Precipitation and Adsorption 5. Chemical Precipitation and Aerobic Treatment 6. Chemical Precipitation, Aerobic Treatment and Adsorption	Laundry	**COD (%)** / **PH (%)** / **Turbidity (%)** / **Total Dissolved Solids (%)** 56.25 / 31.04 / Increase / Increase 50,051 / 7,9 / 26,94 / 4,39 74,18 / 5,9 / 22,28 / Increase 97,55 / 34,31 / 99,82 / 38,81 77,7 / - / - / - 99,86 / 33,3 / 99,75 / 82,28	2020	[33]
Electro-Hybrid Ozonation–Coagulation process	Laundry	Removal of surfactants and microplastics is over 90%...	2022	[34

Tablo [2] Literatürden Çalışmalar

Treatment Methods	Wastewater	Efficiency	Year	References
Hybrid process combining ultrafiltration and electro-oxidation	Laundry	COD (Chemical Oxygen Demand) and nonylphenol ethoxylate removal 97% degradation of NPEO3-17 and 61% degradation of COD	2024	[35]
The peroxy-coagulation process has been developed with iron anodes and carbon-polytetrafluoroethylene cathodes.	Laundry	Removal of surfactants and COD 67-95%	2020	[13]
For high levels of purification, a sand filter can be combined with additional purification techniques such as ultrafiltration, electrocoagulation.	Laundry	**Color:** Significant decrease (exact percentage data not available). **PH:** 13.47% decrease **TSS (Total Suspended Solids):** 29.37% decrease **TDS (Total Dissolved Solids):** 68.65% decrease **Turbidity**: 17.91% decrease **Electrical Conductivity:** 3.89% increase **DO (Dissolved Oxygen):** 79.25% decrease **Iron:** 31.58% increase **Cu (Copper):** 16.67% increase **Mg (Magnesium):** 100% decrease (no change since initial value is 0 mg/L)	2020	[36]
Fixed bed column adsorption study using natural biomass obtained from chemically treated sugar cane pulp	Laundry	Detergent and COD : The best removal efficiency was observed as 65% at 50 mg/L concentration and 10 cm bed height. This was followed by 33% and 20% removal at 4 cm and 2 cm bed heights, respectively. At 250 mg/L concentration, the best removal efficiency was found as 58% at 10 cm bed height, followed by 26% and 17% removal at 4 cm and 2 cm bed heights, respectively.	2019	[37]
Adsorption with polymeric composites and optimization of the process	Laundry	Accordingly, the most effective factors were calculated to be the amount of adsorbent (82%) in detergent removal and the mixing speed (31%) in COD removal; pH was the second most effective factor for both processes.	2021	[38]
Ozonation Treatment, Advanced Oxidation Process	Laundry	70-100% Surfactant, Detergent	2021	[39]
Electroflotocoagulation and Adsorption	Laundry	1. At a current density of 80 A/m², it was observed that synthetic surfactants and color were removed by 80% and turbidity by 85%. 2. The deeper post-water treatment in the adsorption column following the electroflotocoagulation reactor provided 95% removal of synthetic surfactants and color and 97% turbidity. 3. The energy saving rate was approximately 50%.	2022	[40]
Electrocoagulation	Laundry	COD, surfactant, Total Dissolved Solids and turbidity reduction were 80.76%, 27.11%, 17.66% and 74.12%, respectively.	2020	[8]
Adsorption, Batch, Activated Carbon (GAC)	Laundry	Research results show that the optimum adsorbent amount is obtained by mixing 12 grams of adsorbent with GAC and zeolite, with a contact time of 150 minutes. Under these conditions, 57.14% reduction in phosphate levels, 63.11% reduction in COD levels and 53.11% reduction in TSS levels were achieved. Phosphate...	2024	[16]
Electric Flocculation	Laundry	In liquid detergent laundry wastewater, COD, LAS and turbidity removal rates were determined as 84%, 93% and 96%, respectively. In powder detergent laundry wastewater, COD, LAS and turbidity removal efficiencies were 80%, 83% and 91%, respectively.	2021	[40]

3. RESULT

The treatment of laundry wastewater has become a pressing environmental necessity due to the presence of a wide range of harmful pollutants, particularly detergents, surfactants, phosphates, oils, microplastics, and other toxic substances. These pollutants, if released untreated into the environment, lead to serious ecological consequences such as eutrophication, oxygen depletion, and biodiversity loss. They can harm aquatic life, degrade water and soil quality, and disrupt the overall balance of natural ecosystems.

As the complexity and volume of laundry wastewater increase, especially in industrial and hospital settings, the demand for efficient and sustainable treatment solutions has grown significantly. Over the past years, researchers and engineers have developed various physical, chemical, biological, and hybrid treatment methods tailored to the specific characteristics of laundry effluents. Each technique offers distinct advantages based on the type of contaminants present, treatment objectives, operational conditions, and resource availability.

Advanced oxidation processes (AOPs), electrochemical methods, adsorption, and membrane-based technologies have demonstrated high removal efficiencies for surfactants, COD, BOD, and phosphorus compounds. Hybrid approaches, combining methods such as MBBR with UV/O_3 or electrocoagulation with adsorption, have shown enhanced treatment performance and energy efficiency. These methods not only reduce the pollutant load but also offer the potential for water reuse, contributing to water conservation goals.

Choosing the appropriate treatment method requires careful evaluation of the wastewater's composition, economic feasibility, environmental impact, and the desired quality of the treated water. This study has highlighted the effectiveness of various innovative technologies and provided comparative insights through literature-based data and performance outcomes. Ultimately, the successful management and treatment of laundry wastewater play a vital role in protecting ecosystems, supporting public health, and promoting sustainable development in the water sector.

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A MICROCONTROLLER-BASED FIBER-OPTIC DATA COMMUNICATION MODULE FOR TRANSMITTING DATA BETWEEN TWO COMPUTERS

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Abstract
In this work, we present a microcontroller-based fiber optic data communication module. The user interface was prepared using *Visual C# .NET*. For communication module, we used a microcontroller with*Cortex-M0* architecture. The electrical signals were converted into ligth signals via a fiber-optic transceiver pair connected to the internal USART module of the microcontroller. The data transfer between two computers was established by the modules connected to the USB port. Duplex and asynchronous data transfer can be realised with this system. The main novelty of our data transfer system compared to the state-of-the-art is that it utilizes *mbed* platform and uses an industrial microcontroller. Our system alsodoesn't need an extra programming hardware because the microcontroller used in this study has the *USB Bootloader* feature.
Key Words: Cortex-M0, LPC11U23, Serial Communication, Fibe-Optic Data Transmission, Data Transmission Between Computers, Microcontroller-Based Data Transmission

I. Introduction

First use of light for data transmission was with the equipment called *Photophone*, invented by Graham Bell. *Graham Bell* used daylight as the carrier signal and achieved transmission of acoustic signals to a distance of about 200 meters [1]. In 1854, *John Tyndall*demonstrated that light can be guided in the water flow.This phenomenon is now called guiding the light through total internal reflections [2]. After invention of lasers as powerful light sources by *Maiman* in 1960, transmission of data over long distances by modulation of the laser rays became an emerging research area [3]. The company*Corning Glass Works Fiber* was the first one to conduct research on the use of fiber-optic cable for lossless data transmission. This company introduced optical fibers with a loss factor of 10 dB per km in 1970 [4]. Thanks to rapid advances of the field, fiber- optic cables with a loss factor of 0.1 dB/km made of pure glass are produced today and fiber-optic communication systems can reach up to 14 Tbits/s in bandwidth and 160 km in distance [5]. Fiber-optic cables are light waveguides operating by the principle of total internal reflection [6, 7]. Today telephone conversations, terrestrial television broadcasting and transmission of digital data generated by the computers (Internet) are performed with high capacity fiber-optic communication systems in a safe, fast and efficient fashion. The aim ofthis study is to create a fiber-optic communication system for data
transmission between computers. Its superiority over the existing systems is that it is based on an industrial microcontroller and utilizesthe *mbed* platform, allowing rapid prototyping without the need for extra debugging equipment [14-18].

II. Materials and Methods

2.1 System Architecture

Project has two main components: hardware and software. The hardware partconsists of the fiber-optic communication module, which is interfaced to the computer via the USB port. This hardware is mainly responsible for sending and receiving data. The software component comprises of the software on the microcontroller of the communication module and the user interface on the computer.

2.2 Hardware Components

- Fiber-Optic Communication Module

This module connects two computers via a fiber-optic cable and converts data from the computer to light signals. The most important components of this module are the microcontroller and the fiber-optic transceiver. Other circuit elements assume secondary functions such as electrical protection, voltage regulation, generation of clock pulse and USB connection. Fiber-optic communication module is shown in the Figure 1 and the circuit schematics are shown in the Figure 2a and Figure 2b.

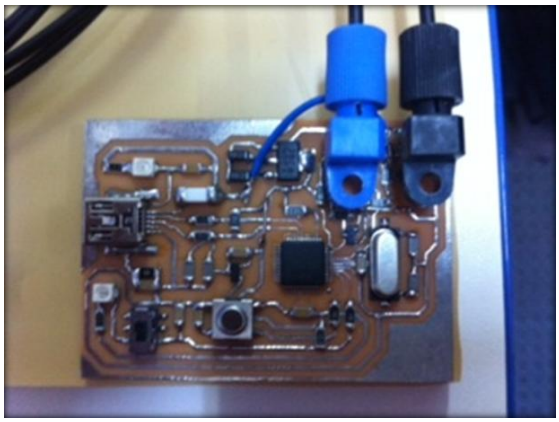

Figure1. Fiber Optic Communication Module

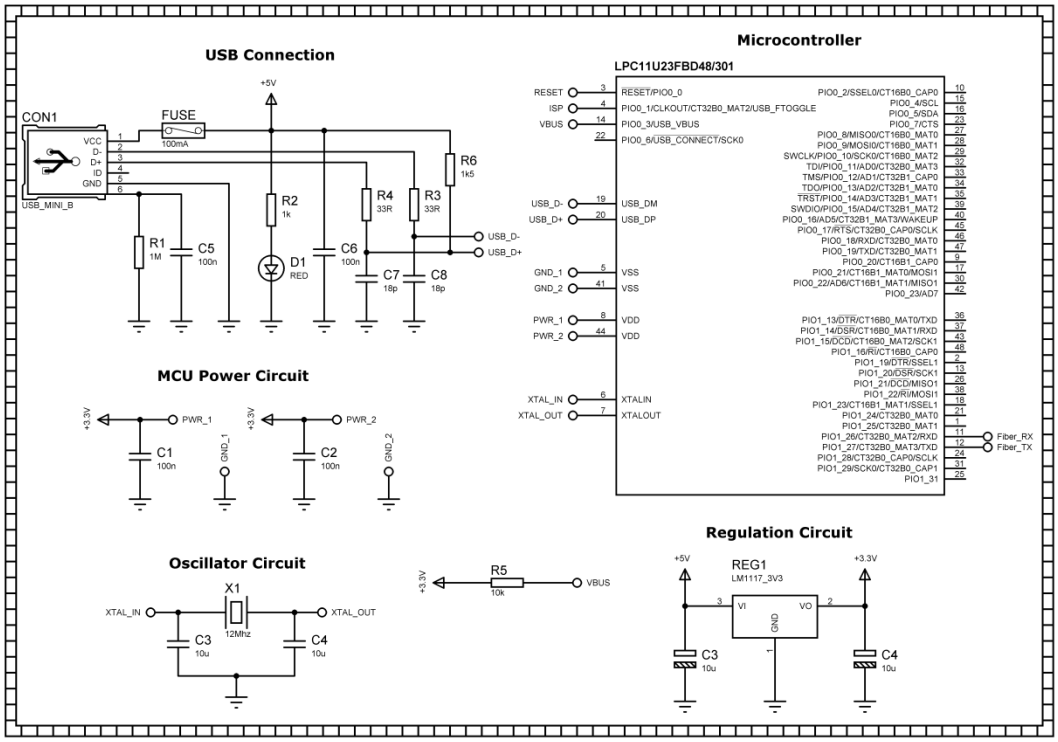

Figure 2a. Circuit Diagram of Fiber Optic Communication Module: USB Connection, Microcontroller, Power Circuitry, Oscillator and Regulators.

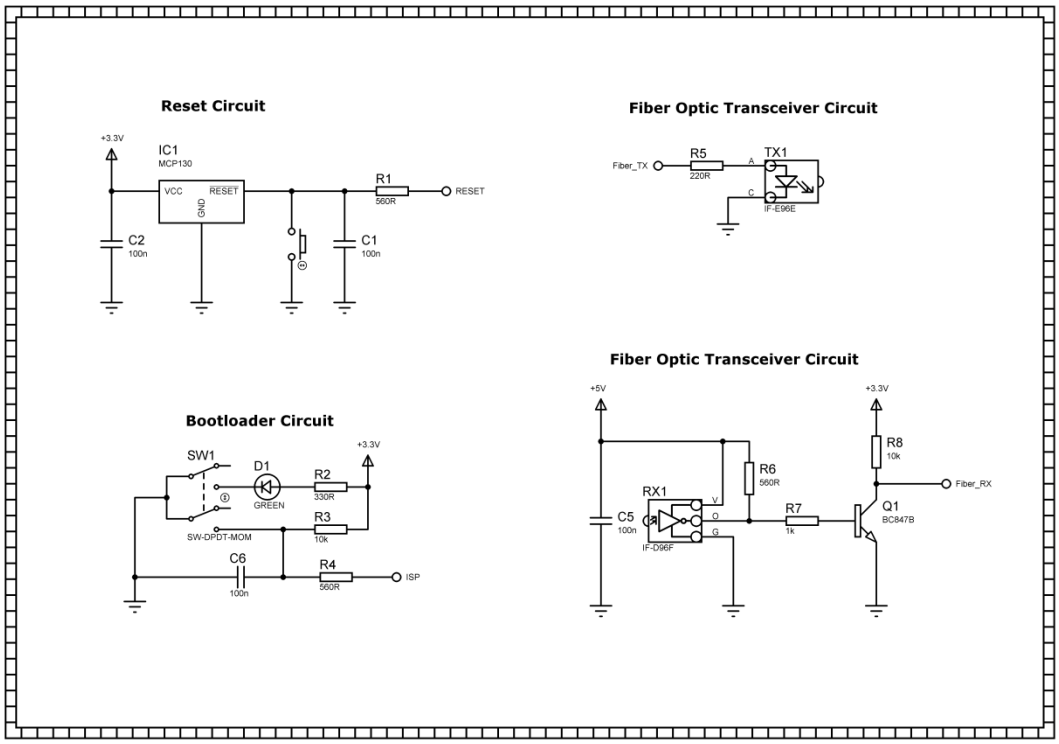

Figure 2b. Circuit Diagram of the Fiber-Optic Communication Module: Reset Circuit, Fiber-Optic Transceiver and Boot-loader.

- Microcontroller

This work uses the microcontroller *NXP LPC11U23* with 32-bit architecture. Since NXP microcontrollers are used in a multitude of industrial applications with proven reliability,

affordable price and performance, we chose*LPC11U23*as the microcontroller of this study. The microcontroller also has various complex peripheral units (USB, USART, A DC, etc.) and is capable of operating at high speed, and can be directly programmed thanks to the software USB Bootloader. Detailed documentationis provided by the manufacturer for product selection, design and programming. Software for this microcontroller can also be developed independent of hardware thanks to the application-programmer interface *CortexMicrocontroller Software Interface (CMSIS)* [8, 9]. In this work, we used the built-in USB and USART peripherals of the microcontroller. The computer was made to recognize the microcontroller as a virtual serial port. The incoming and outgoing data were transmitted using this configuration. Direct software updating through USB connection was enable by setting the microcontroller In-System-Programming (ISP) mode. Block diagram of the microcontroller is shown in the Figure 3.

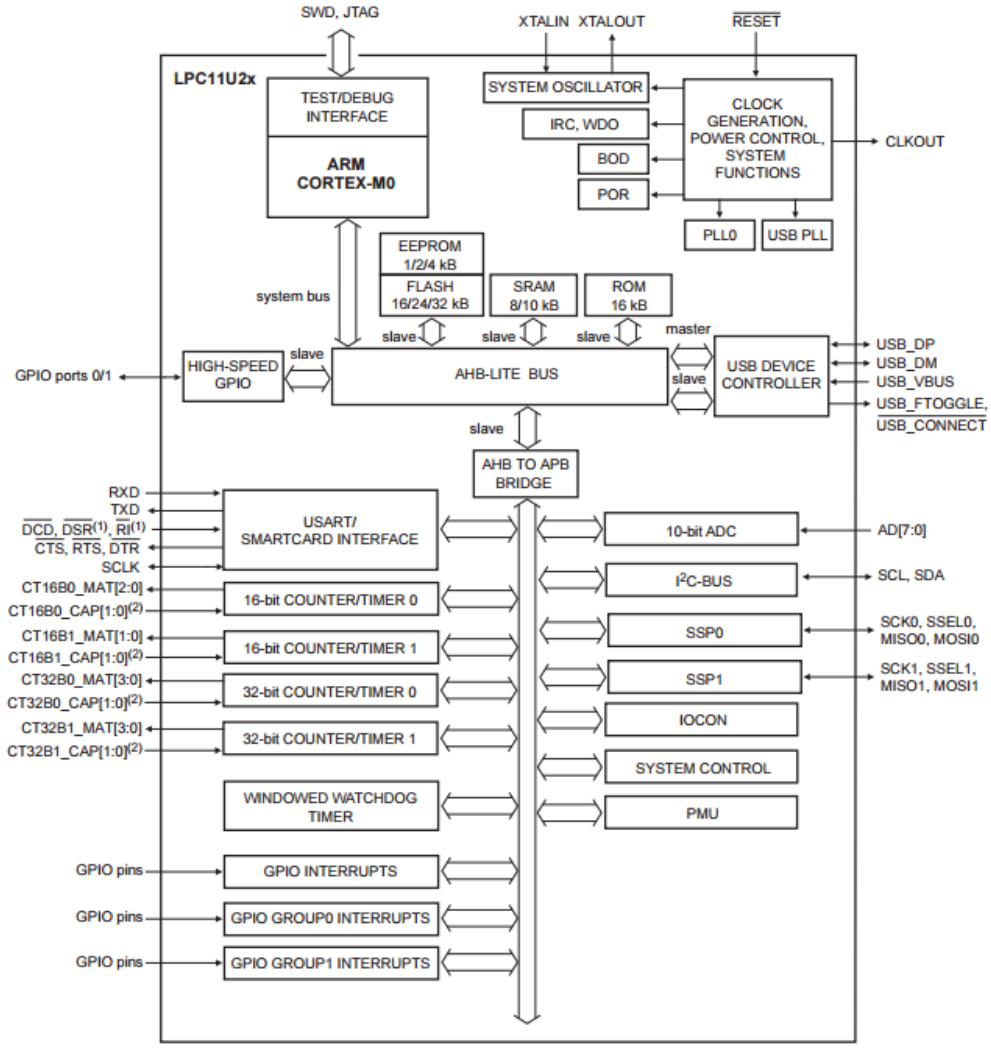

Figure 3. Block Diagram of the NXP LPC11U23 Microcontroller. [11]

➢ Fiber Optic Transceiver

In order to transfer data received from the computer by the microcontroller via the fiber-optic cable, a transmitter module converting electrical signals to light signals and a receiving module converting the light signals to electrical signals are required. There are modules made by different manufacturers which are compliant with the standard fiber-optic cable sockets. However due to the high cost of these, modules with plastic enclosure retaining fiber cable by means of the hook structure were preferred in this study. The modules used in this project are transmitter *IF-E96E*

and receiver module*IF-D96F*manufactured by *Industrial Fiber Optics*. These modules are capable of carrying both digital signals and digitalized analog signals.

- IF-E96E

IF-E9E accommodates a photodiode with wavelength of 645nm emitting red light as well as a lens that captures the emitted light and transfers it into the fiber at an appropriate critical angle [10].

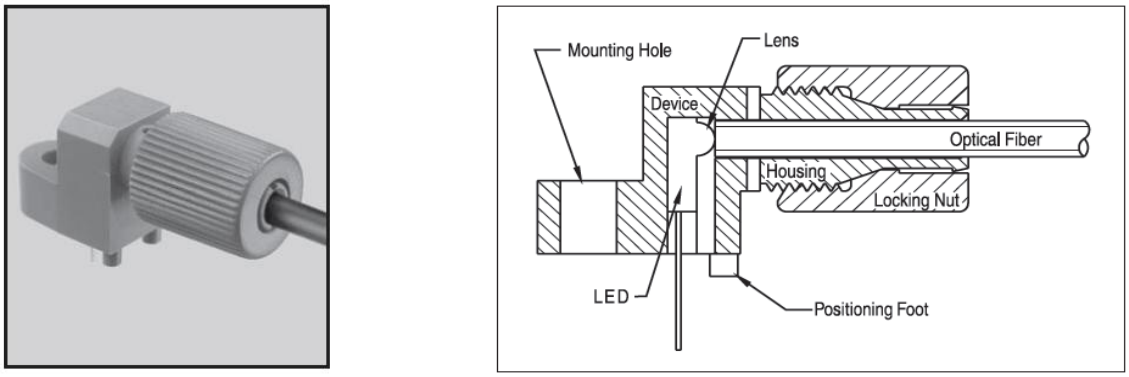

Figure 4. IF-E96E Transmitter Module [10].

- IF-D96F

IF-D96F has a lens capturing rays from the fiber-optic cable and sending them on a light-sensitive semiconductor, amplifier circuit, voltage comparator and a Schmit trigger circuit to obtain binary logic signal. Since IF-D96F takes the complement of the signal before sending to the output, the complement of the signal has to be taken before sending it to the microcontroller [10].

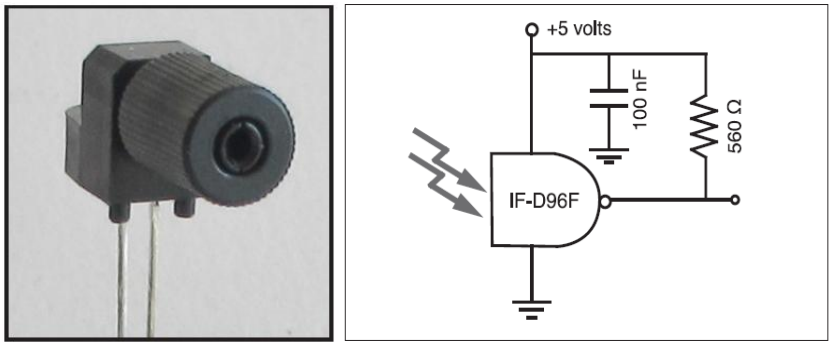

Figure 5. IF-D96F Receiver Module and Typical Application Circuit [10].

➢ Design of Printed Circuit Board

The circuit schematics and printed circuit board (PCB) layout of the fiber-optic communication module was prepared using ARES platform of Proteus. All electronic components of the circuit are surface mount components. PCB is design as a single layer with three bypasses. PCB layout is shown in Figure 6.

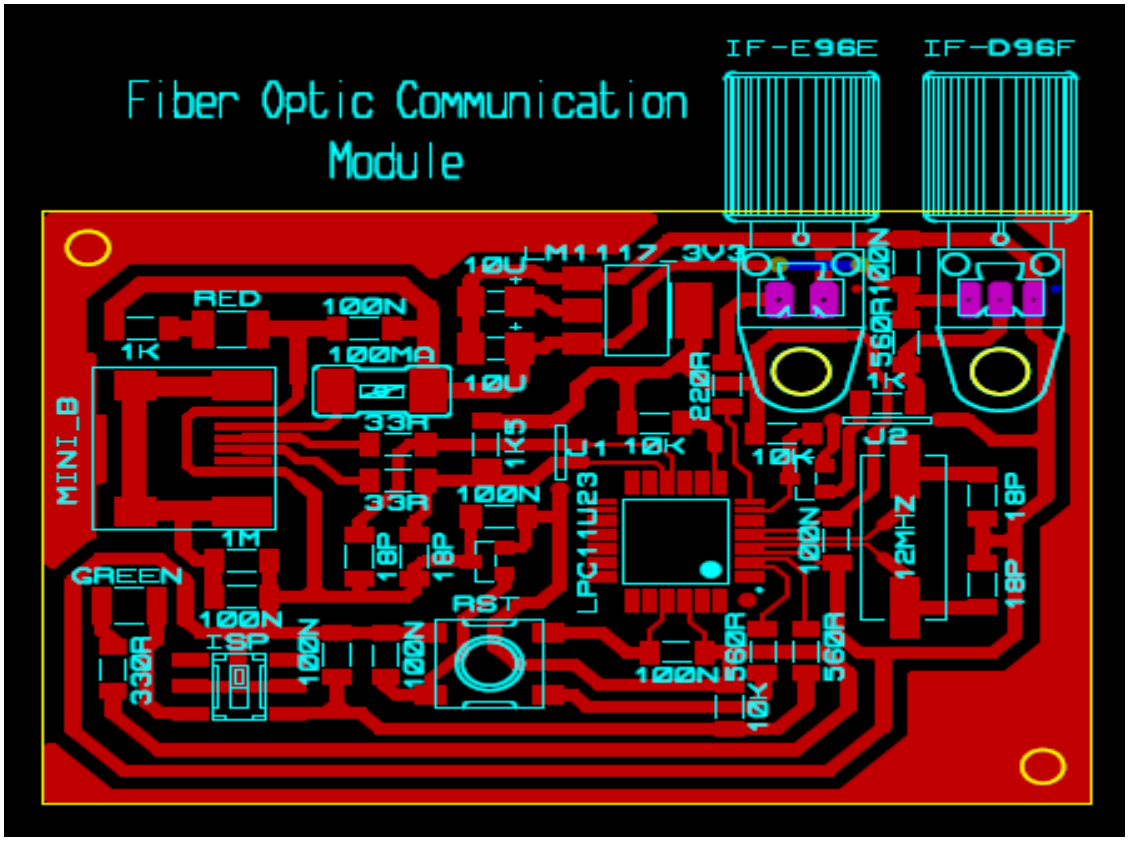

Figure 6. Fiber-Optic Communication Module PCB Layout.

2.3 Components of Software

➢ Microcontroller Software

Software of the microcontroller used in this project was developed by using *mbed* platform with the online*C++* compiler. *mbed* supports software development kits by the manufacturers such as *NXP*, *Freescale* and *Axeda*, and allows rapid prototyping for the application engineers. Thanks to its performance and flexible software interface, embedded system software can be developed without writing low-level system software and tackling with hardware specifications. *Mbed* Real Time Operating System (RTOS)facilitates development of multi-threaded applications. *mbed* has open-source code license [11]. Official software library of *mbed* and *USB Device* library were used in the software development for this project.

MCU sends and receives the incoming or outgoing data via virtual serial port through the fiber optic transceiver connected to the USART module. The default serial communication settings of the libraries were used for this duplex communication (Baudrate=9600, Parity=None, Databits=8, Stopbits=1). The microcontroller software used in this project is provided in Appendix A. A file with .BIN extension was created with the online compiler and was loaded to the microcontroller LPC11U23 via USB port by using the *NXPISP* program. For programming, the microcontroller should enter to the mode *USB_ ISP_Bootloader*. In order to make the controller enter into this mode, the ISP end should be brought to logical 0 and that of *USB_VBUS* should be brought to the level of logic 1 when the circuit is de-energized. In such case, when USB connection is established, the microcontroller is perceived by the computer as a mass storage device, making it possible to replace the file named *firmware.bin*with a new one [12].

➢ User Interface

System interface was prepared on the platform *Visual Studio 2010 Ultimate* by using Visual C# language. Graphic interface of the program has a tab for the settings of the connection Serial

Port and fields for displaying the received data. The user is notified about the process status by means of a message board. Data receiving and sending functions of the serial port are operated asynchronously by using two different *Background Worker* objects.

- Usage of the User Interface Software

Working principle of the Fiber-Optic Communication Module is summarized in the following ten steps:

Step 1: Computer 1 and Computer 2 connects each other with Fiber-Optic Communication Module for data exchange.
Step 2: Fiber Optic Communication Software setup file runs in Computer 1 and Computer 2.
Step 3: Before the start of the data exchange, Computer 1 and Computer 2 sets some parameters about RS232 (COM PORT, BAUDERATE etc.)
Step 4: After the selection of parameters, click the connection button on the software.
Step 5: Port status is checked.
Step 6: If there is no problem with the connection, data exchange screen can be used for data send and receive.
Step 7: To transfer data, a file with .txt extension can be called from the program or written directly on the message screen. Then the transmission is started by pressing the send button.
Step 8: The data sent by the computer 1 can be seen simultaneously on the Computer 2 screen.
Step 9: Incoming data can be saved in a text file if desired.
Step 10: This registration and submission can be done in both ways between computers.

III. Experimental Results

Transmitter and receiver software interface of the fiber-optic communication module is shown in Figure 7. This software allows sending data from the computer 1 to computer 2and vice versa.

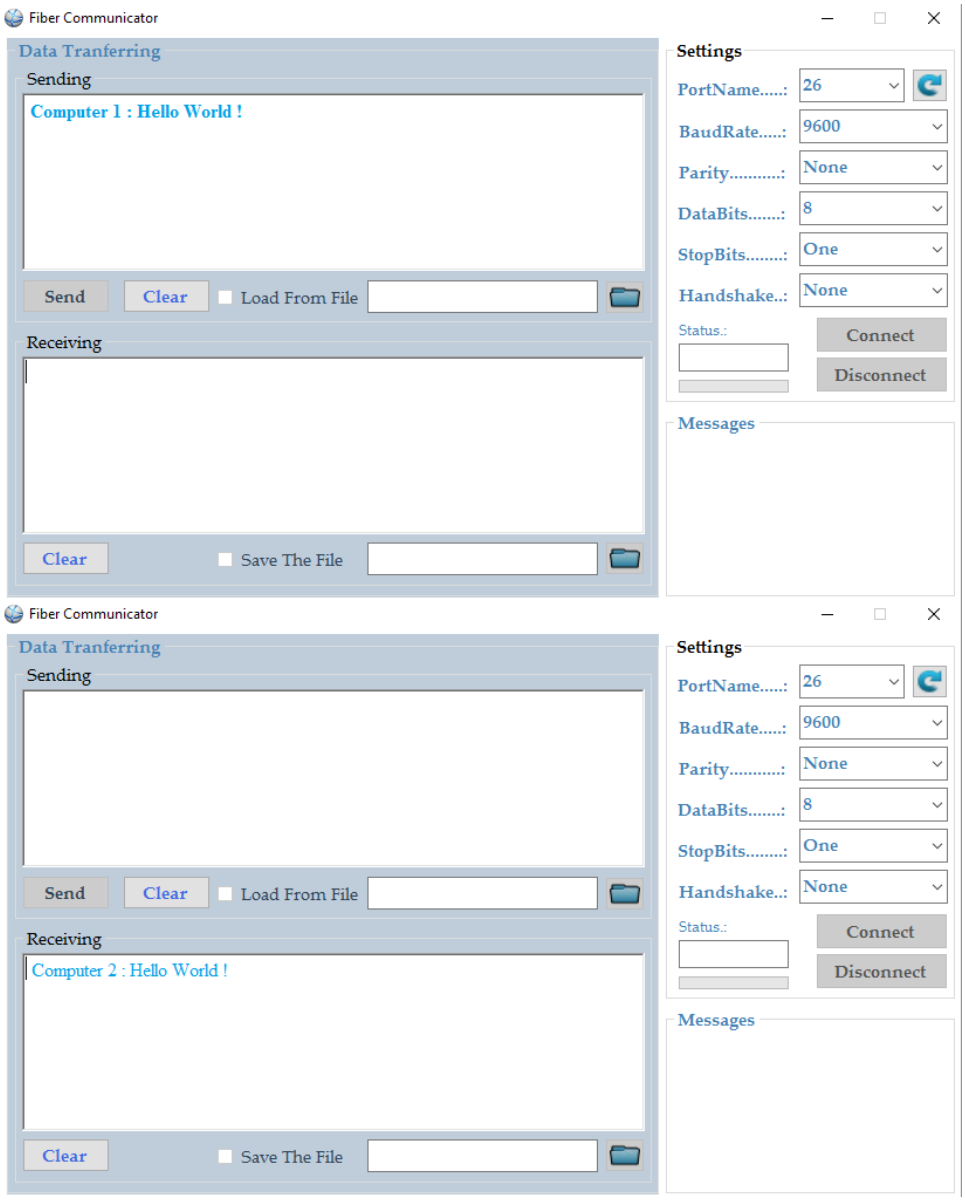

Figure 7. Fiber-Optic Communication Software Interface.

We set up a simple test system to verify the operational performance of the fiber-optic communication modules.We tested whether the modules can transmit data correctly between two computers at different communication speeds. We performed tests in both directions. The baudrate values used during the tests are given in Table 1. According to Table 1, data transmission between modules was successful in both directions at communication speeds up to 38400 baud. When 38400 baud value was exceeded, seventy five percent of the data transmission was interrupted.We hypothesize that the main reason for these problems in data communication is the computer software rather than the data transmission capacity of the fiber optic transceiver pair.

Table 1: Test Results

Communication Speed (Baud)	Number of Characters	TEST 1	TEST 2	TEST 3	Direction
2400	100	Success	Success	Success	PC_1 To PC_2
4800	100	Success	Success	Success	PC_1 To PC_2
9600	100	Success	Success	Success	PC_1 To PC_2
14400	100	Success	Success	Success	PC_1 To PC_2
19200	100	Success	Success	Success	PC_1 To PC_2
28800	100	Success	Success	Success	PC_1 To PC_2
38400	100	Success	Success	Success	PC_1 To PC_2
57600	100	Success	Fail	Success	PC_1 To PC_2
76800	100	Success	Fail	Fail	PC_1 To PC_2
115200	100	Success	Success	Fail	PC_1 To PC_2
230400	100	Success	Fail	Fail	PC_1 To PC_2
2400	100	Success	Success	Fail	PC_2 To PC_1
4800	100	Success	Success	Success	PC_2 To PC_1
9600	100	Success	Success	Success	PC_2 To PC_1
14400	100	Success	Success	Success	PC_2 To PC_1
19200	100	Success	Success	Success	PC_2 To PC_1
28800	100	Success	Success	Success	PC_2 To PC_1
38400	100	Fail	Success	Success	PC_2 To PC_1
57600	100	Fail	Success	Success	PC_2 To PC_1
76800	100	Fail	Success	Success	PC_2 To PC_1
115200	100	Fail	Fail	Success	PC_2 To PC_1
230400	100	Success	Fail	Fail	PC_2 To PC_1

V. Conclusions

In this study, unlike the existing studies in the literature, a fiber-optic communication network was established between two computers by using a microcontroller with ARM Cortex-M0 architecture. In light of information obtained from this study, modules compliant with the standard communication protocols ad capable of carrying data without being affected by noise in the industrial environments can be designed cost-effectively. Similarly, data acquisition cards with increased real-time control performance can be realized thanks to the rapid and reliable dataflow of fiber-optic communications. In this study it was also shown that, data transmission was successful in both directions at communication speeds up to 38400 baud.

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DEVELOPMENT OF TECHNOLOGY FOR IN VITRO PROPAGATION AND STORAGE OF ATROPA BELLADONNA L.

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Abstract
Bulgaria is relatively small in area, it has a rich biological diversity due to the highly varied climatic, geological, topographical and hydrological conditions. The Bulgarian flora is a source of plant species rich in a large set of chemical components – specific substances or groups of compounds that are in limited populations. The species Atropa belladonna L. is distributed in forested areas throughout the country. Due to the presence of atropine and scopolamine, the herb is highly poisonous. The application of modern reproductive technologies provides a chance to evaluate, characterize and preserve the species Atropa belladonna, study them under controlled conditions and return them to their natural habitats for the purpose of their preservation. The effect of BAP on the regeneration response of explants was studied using concentrations of 0.5; 0.7; and 1.0 mg/l. Murashige and Skoog (1969) medium. The best development of the species is reported on the 20th and 30th day on Murashige and Skoog (1962) medium containing 0.5 mg/l BAP. The multiplication factor for this variant is 1:5, and for the control variant 1:4. With increasing observation period, the leaf number indicators change significantly. The low concentration of the studied cytokinin does not allow A. belladonna to realize the maximum of its development potential in controlled conditions.
Keyword: plant genetic resources, in vitro, Atropa belladonna L., BAP, micropropagation

INTRODUCTION

Herbs play an important role in the prevention and treatment of many diseases. Over 80% of the world's population uses medicinal plants, and according to the World Health Organization, this percentage is constantly growing. Herbs used to prepare medicinal preparations account for nearly 40% of the pharmaceutical industry.

Bulgaria is relatively small in area, it has a rich biological diversity due to the highly varied climatic, geological, topographical and hydrological conditions. The Bulgarian flora is a source of plant species rich in a large set of chemical components – specific substances or groups of compounds that are in limited populations.

In recent years, there has been a successful interaction between traditional and folk medicine. This gives good results in the treatment of various diseases. People's interest in medicines of plant origin is increasing. A small part of the herbs exported from Bulgaria are cultivated. They are mainly collected from their habitats. In the localities, medicinal plants are protected from damage and destruction in order to ensure their sustainable use as part of a plant genetic fund with future value.

The species Atropa belladonna L. is widespread in forested areas throughout the country. Due to the presence of atropine and scopolamine, the herb is highly poisonous. The alkaloids contained in it have a painkilling effect.

The ever-decreasing number of natural habitats of Atropa belladonna necessitates the search for other methods for the conservation of the species. The application of modern reproductive technologies provides a chance for the evaluation, characterization and conservation of the species Atropa belladonna, study under controlled conditions and their return to natural habitats for the purpose of their conservation.

The introduction of Atropa belladonna into in vitro conditions was first reported in 1957 (Volossovic, 1970). Studies on the development of Atropa belladonna in vitro conditions on Murashige & Skoog culture medium were carried out by Taha (2003).

According to Hank et al. (2003), very good results in the cultivation of the species Atropa belladonna are observed in ½ MS medium containing 3% sucrose.

BAP (6-benzylaminopurine) is a synthetic cytokinin. A purine compound that stimulates cell division and is (often) included in the composition of in vitro culture media to slow down the aging process. At higher concentrations (above 3–4 mg/l) it can stimulate the formation of adventitious shoots and suppress root formation (Skoog, 1957; Holub et al., 1998).

Studies on the use of BAP in culture media range from 0.1 mg/l to 0.5–2.0 mg/l (Orlikowska et al., 1991; Mateikiene et al., 1996).

Polikarpov (1986) points out that during longer cultivation of explants in nutrient media containing BAP concentrations of 2.5–3.0 mg/l, a retardation in the development of microplants is observed and, when transferred to a rooting medium, they do not form roots and die.

The use of higher concentrations of BAP in the species Atropa belladonna L. characterizes the development of an axillary meristem and the formation of multiple lateral branches (Benjamin et al., 1987), and according to the authors Vysotsky et al. (1976) the addition to the culture medium leads to a positive effect on morphogenesis and stimulates leaf formation.

Possibilities for in vitro propagation and study of the reaction of the medicinal species Atropa belladonna L., growing under controlled conditions, on MS nutrient medium with the participation of BAP at a concentration of 0.5 mg/l and IAA– 1.0 mg/l, were studied by Dimitrova et al. (1996).

MATERIAL AND METODS

The research was conducted for a year in the Tissue Culture Laboratory at the Institute of Plant and Genetic Resources "Konstantin Malkov" - town of Sadovo. Plant material of the

species Atropa belladonna L. was provided after an expedition to the Beglika area in the Rhodope Mountains.

As starting material, tips and cuttings of young shoots of Atropa belladonna plants were taken during the months of April and May. The plant explants were disinfected with 70% C_2H_6O for 1 minute, washed with sterile distilled water, 5% CaOCl for 8-10 minutes and subjected to three washings with sterile distilled water.

The Atropa belladonna microplants, after the first cultivation, were transferred to modified nutrient media based on Murashige and Skoog, 1962 and added with varying concentrations of 0.5; 0.7; and 1.0 mg/l BAP.

The reading of the established explants was done every 10 days for one month. The experiment was set up in three repetitions.

Grown in a phytostat chamber at 20±22°C and a photoperiod of 16/8 light/dark provided by fluorescent lamps, with white light.

For the control, Murashige and Skoog (1962) was applied without added growth regulators.

Sucrose (30 g/l) and agar (7.0 g/l) were used as carbohydrate sources for the Murashige and Skoog basal medium with a pH of 5.6. Sterilization was performed for 30 min at 120º C and a pressure of 0.9 atm.

RESULTS

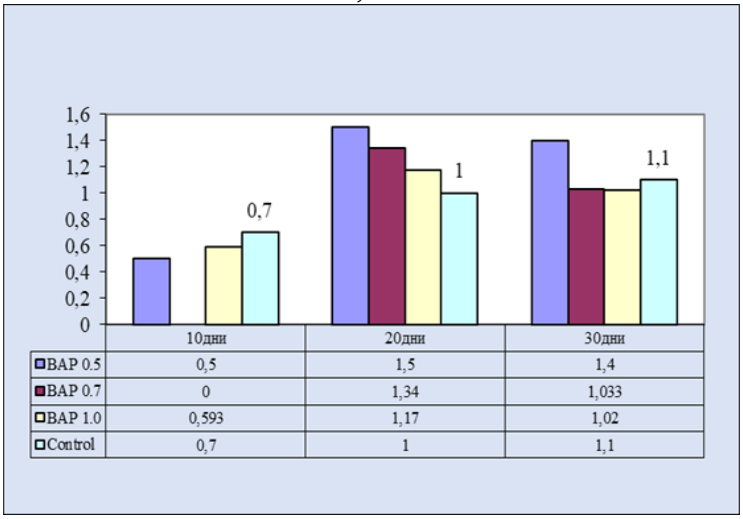
The obtained sterile plant material after undergoing the sterilization procedure is 70%. The explants are vibrant with a green color and have very good development in controlled conditions. The choice of the basic nutrient medium Murashige and Skoog (1962) for micropropagation of Atropa belladonna was made based on preliminary studies of their effectiveness.

The main component that determines plant growth at this stage is the concentration of BAP. The synthetic cytokinin eliminates apical dominance, thus inducing the development of lateral buds and starting the process of proliferation of new plants. In all three used concentrations of 0.5; 0.7 and 1.0 mg/l in Murashige and Skoog (1962) culture medium of the cytokinin BAP and in the control variant, very good development was reported in terms of the height of the explants on the 10th day after the experiment was started. Lack of development of the explants was observed in the initial stage of development in the variant with the participation of 0.7 mg/l, with the highest development value in the control variant. (Table 1).

Photo 1 The species Atropa belladonna on the 20th day of the experiment in a variant with the participation of 0.5 mg/l BAP

With increasing observation period, the growth values of the explants are with different measurements. The best development of the species is reported on the 20th and 30th day on

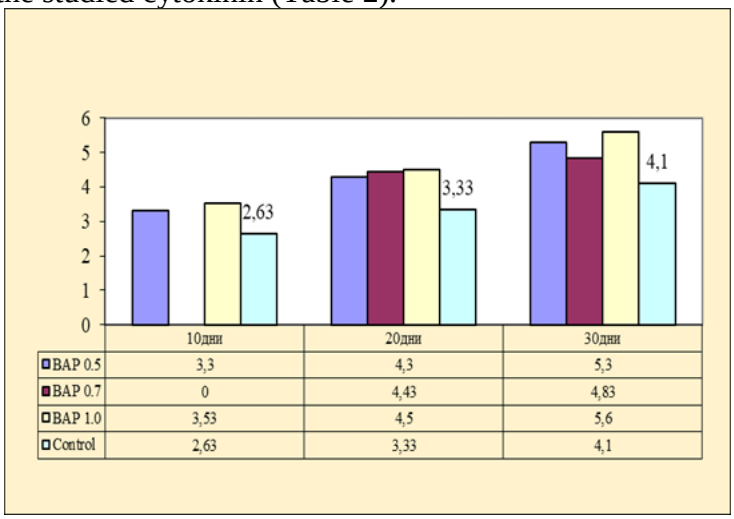
Murashige and Skoog (1962) nutrient medium with the participation of 0.5 mg/l BAP (photo.1). The multiplication factor for this variant is 1:5, and for the control variant 1:4.



	10дни	20дни	30дни
BAP 0.5	0,5	1,5	1,4
BAP 0.7	0	1,34	1,033
BAP 1.0	0,593	1,17	1,02
Control	0,7	1	1,1

Table 1 Effect of the cytokinin BAP at concentrations of 0.5, 0.7 and 1.0 mg/l with hormone-free medium on the explant height indicator in Atropa belladonna L.

The effect of cytokinin BAP on the number of leaves was measured on the 10th day of the experiment in the variant with the participation of 0.5 mg/l BAP. No leafing of the explants was observed in 0.7 mg/l BAP. The probable reason for this result is the lack of influence on the growth process of the studied cytokinin (Table 2).



	10дни	20дни	30дни
BAP 0.5	3,3	4,3	5,3
BAP 0.7	0	4,43	4,83
BAP 1.0	3,53	4,5	5,6
Control	2,63	3,33	4,1

Table 2 Effect of the cytokinin BAP at concentrations of 0.5, 0.7 and 1.0 mg/l with hormone-free medium on the leaf number indicator in Atropa belladonna L.

On the 20th day of the experiment, the three concentrations studied had almost identical results, exceeding the control variant. In all three concentrations of the studied cytokinin, approximately the same development indicators are reported with increasing time. The control variant is distinguished by low indicators of realization of the genetic indicator of the species.

It is impressive that the low concentration of the studied cytokines gives a satisfactory result for maximum leaf formation. This shows that the medicinal species would respond very well in future studies with lower concentrations of BAP .

Their refined parameters in the study of Atropa belladonna and their application with specific values depending on the biological specificity create the opportunity to optimize the process - a high degree of realization of the potential of the explants, good stimulation of growth

processes and a satisfactory multiplication coefficient. This information is the basis for completing the entire technological cycle for industrial in vitro propagation. The results obtained will also serve as a basis for continuing scientific research work with this plant species in introducing new varieties into in vitro culture and testing in vitro storage methods.

CONCLUSION

Based on the observation conducted on Murashige and Skoog (1962) nutrient medium with the participation of 0.5, 0.7 and 1.0 mg/l BAP, we establish that the indicators of realization of the species Atropa belladonna L. are optimal at the concentration of 0.5 mg/l BAP.

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THE IMPACT OF THE MEDITERRANEAN DIET ON AUTOIMMUNE DISEASES: A SYSTEMATIC REVIEW AND ANALYSIS

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Abstract
In this presentation, we explore the potential of the Mediterranean diet (MD) in the management of autoimmune diseases. Emerging evidence suggests that MD may play a significant role in reducing disease activity and modulating inflammatory processes. We present findings from a systematic review of recent studies, with particular focus on key dietary components such as dietary fiber, omega-3 fatty acids, polyphenols, resveratrol, vitamins, and essential micronutrients. Our analysis highlights how these components contribute to the anti-inflammatory and immunomodulatory effects observed in conditions like rheumatoid arthritis, systemic lupus erythematosus, and spondyloarthritis. While the results are promising, further research is needed to clarify the underlying mechanisms and to determine optimal dietary strategies. We also touch upon the importance of integrative approaches, combining diet with exercise and stress management, as a promising direction for future clinical applications. This presentation aims to offer new insights into how the Mediterranean diet can be effectively integrated into the therapeutic landscape of autoimmune disease care.
Keywords: Mediterranean diet, autoimmune diseases, rheumatoid arthritis, systemic lupus erythematosus, spondyloarthritis, dietary components, micronutrients, antioxidants, anti-inflammatory effects
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INTRODUCTION

Autoimmune diseases encompass a broad spectrum of disorders in which the immune system mistakenly attacks the body's own tissues (Albarbar & Aga, 2024). These diseases include conditions such as rheumatoid arthritis (RA), systemic lupus erythematosus (SLE), Hashimoto's thyroiditis, Sjögren's syndrome, and systemic sclerosis (SSc). The traditional treatment of autoimmune diseases primarily involves the use of immunosuppressive drugs aimed at suppressing the immune response (Chandrashekara, 2012). However, in recent decades, increasing attention has been paid to nutritional and lifestyle approaches as adjunctive therapies, which may help reduce disease activity and improve quality of life (Gioia et al., 2020; Isola et al., 2024).

The Mediterranean Diet is a dietary pattern rich in fiber, plant-based foods, olive oil, fish, and fruits, and has been extensively studied for its potential health benefits (Ungvari et al., 2024). Research has shown that the MD may have favorable effects on autoimmune diseases (Fekete et al., 2023; Vieira et al., 2014). This diet is characterized by its anti-inflammatory and antioxidant properties, which could influence immune responses and potentially alleviate symptoms of autoimmune disorders (Madarász et al., 2023). In this article, we will explore the impact of the Mediterranean Diet on autoimmune diseases, with a particular focus on the underlying immunological mechanisms and the scientific evidence supporting its potential therapeutic benefits.

Recent studies have suggested that the Mediterranean Diet, with its emphasis on healthy fats, antioxidants, and anti-inflammatory compounds, could play a significant role in modulating immune function, improving the balance of gut microbiota, and reducing systemic inflammation (Barrea et al., 2021). The Mediterranean diet, rich in polyphenols, omega-3 fatty acids, and vitamins, offers a promising approach to managing autoimmune diseases, as it not only promotes immune system modulation but also addresses factors such as oxidative stress, gut health, and inflammatory pathways. (Román et al., 2019)

Through this article, we will delve deeper into the current evidence regarding the Mediterranean Diet's role in managing autoimmune diseases, examining its potential as a complementary treatment strategy and its possible benefits in improving patient outcomes.

METHODS

In this article, we conducted a comprehensive review of scientific literature to assess the potential impact of the Mediterranean Diet on autoimmune diseases. A systematic search of relevant studies was performed using three major online databases: PubMed, Web of Science, and Scopus. The search terms included combinations of keywords such as "Mediterranean Diet", "autoimmune diseases", "rheumatoid arthritis", "lupus", "Sjögren's syndrome", "Hashimoto's thyroiditis", "systemic sclerosis", "dietary interventions", and "inflammation". Only peer-reviewed articles published in English were considered.

RESULTS

The Mediterranean Diet: components and mechanisms of action

The Mediterranean Diet is a plant-based dietary pattern that emphasizes the consumption of vegetables, fruits, legumes, nuts, whole grains, and moderate amounts of fish and seafood. At the core of this dietary pattern is the use of extra virgin olive oil as the primary source of fat, which contains numerous bioactive compounds, including phenols, carotenoids, and triterpenoid alcohols. These compounds exhibit potent antioxidant, anti-inflammatory, and immunomodulatory properties, making olive oil an essential component of the MD.

One of the hallmark features of the Mediterranean Diet is its inclusion of moderate wine consumption, particularly red wine, which is rich in phenolic compounds like resveratrol (Santos-Buelga et al., 2021). These compounds contribute to the diet's anti-inflammatory and antioxidant effects, supporting cardiovascular health and potentially modulating immune responses.

The anti-inflammatory effects of the Mediterranean Diet are largely attributed to its positive impact on the gut microbiota (Del Chierico et al., 2014). The gut microbiome plays a pivotal role in the pathogenesis of numerous autoimmune diseases. Dysbiosis, which refers to the imbalance in the gut microbiota, has been shown to exacerbate autoimmune responses. The Mediterranean Diet is rich in prebiotics, such as dietary fibers, which promote the growth of beneficial bacteria, including Bifidobacterium, Lactobacillus, and Faecalibacterium prausnitzii. These bacteria are known to have anti-inflammatory effects and contribute to the regulation of immune responses (Barber et al., 2023; Fekete et al., 2024).

By supporting a healthy and diverse microbiome, the Mediterranean Diet may help reduce the risk of autoimmune disease development and mitigate disease activity in individuals with existing conditions (Tsigalou et al., 2024). Furthermore, the gut's role in modulating immune function highlights the potential of diet, particularly the Mediterranean Diet, in managing inflammation and improving overall immune health (Fekete et al., 2025; Paolino et al., 2019).

In addition to its microbiome-related effects, the Mediterranean Diet's rich content of polyphenols, unsaturated fats, and antioxidant-rich foods further contributes to its ability to modulate inflammation. These mechanisms collectively position the Mediterranean Diet as a promising dietary intervention for managing autoimmune diseases and supporting overall health.

The Mediterranean Diet's impact on rheumatoid arthritis

Rheumatoid arthritis is one of the most common autoimmune diseases, characterized by chronic inflammation of the joints. As an inflammatory disease, RA can lead to pain, stiffness, and long-term joint damage. Over the years, a growing body of research has explored the effects of dietary interventions, particularly the Mediterranean Diet, on RA management, with promising results suggesting that MD can play a key role in mitigating the disease's progression and alleviating symptoms (Cooper & Stroehla, 2003).

Several studies, including a randomized controlled trial by Papandreou and colleagues, have shown that combining the Mediterranean Diet with physical exercise can significantly reduce disease activity (as measured by the Disease Activity Score-28, DAS-28), improve cardiometabolic markers such as weight and blood glucose levels, and alleviate pain (Papandreou et al., 2023). This combination of dietary and lifestyle interventions was also found to enhance physical function, a critical aspect of managing RA, particularly in the context of joint mobility and overall quality of life.

Other studies evaluating the Mediterranean Diet's effects on RA have reported similar findings, emphasizing that adherence to the MD can lead to improvements in disease status while maintaining a healthy weight and reducing systemic inflammation (Tsigalou et al., 2020). These benefits are primarily attributed to the diet's rich content of anti-inflammatory nutrients, such as omega-3 fatty acids, antioxidants, and polyphenols, which play a pivotal role in modulating the immune response and reducing the inflammatory processes that underlie RA (Darlington & Stone, 2001).

A key feature of the Mediterranean Diet is its emphasis on fish consumption, especially fatty fish like salmon, sardines, and mackerel, which are rich in omega-3 polyunsaturated fatty acids (PUFAs) (Fekete et al., 2021) Omega-3s have well-documented anti-inflammatory properties, and several studies have demonstrated their beneficial impact on RA. For example, regular intake of omega-3 fatty acids has been shown to reduce the need for non-steroidal anti-inflammatory drugs (NSAIDs), improve joint pain, and decrease the number of tender joints in individuals with RA (Lee et al., 2012).

The mechanisms by which omega-3 fatty acids exert their effects are multifaceted. These include the reduction of inflammatory cytokines such as interleukin-1 beta (IL-1β), inhibition of leukotriene B4 production, and modulation of T-cell differentiation (Bodur et al., 2024). All of these pathways play critical roles in the inflammatory cascade, which is central to the

pathophysiology of RA. By reducing the activity of these pro-inflammatory molecules, omega-3s can help dampen the immune system's attack on the body's tissues, thus alleviating symptoms and potentially preventing further joint damage (Tiwari et al., 2025).

Sjögren's syndrome

Sjögren's syndrome is primarily characterized by dry eyes, dry mouth, and systemic involvement, including joint pain and fatigue (Negrini et al., 2022). As an autoimmune disorder, it often leads to inflammation of the salivary and lacrimal glands, resulting in the hallmark symptoms of dry mouth and dry eyes. In addition to these symptoms, individuals with pSS may experience other systemic manifestations such as lung and kidney involvement, and there is an increased risk for developing lymphoma (Negrini et al., 2022).

Recent studies exploring the role of diet in the management of pSS have found that fish consumption, which is a key component of the Mediterranean Diet, may have a protective effect on the disease course (Castrejón-Morales et al., 2020). Specifically, the omega-3 fatty acids found in fatty fish like salmon, mackerel, and sardines have anti-inflammatory properties that could potentially mitigate the chronic inflammation associated with pSS. Omega-3 fatty acids have been shown to reduce the production of pro-inflammatory cytokines, which are implicated in the immune-mediated damage characteristic of autoimmune diseases, including pSS (Nave et al., 2024).

Furthermore, adhering more closely to the Mediterranean Diet appears to be associated with a reduction in disease activity in patients with pSS (Carubbi et al., 2021). The diet's emphasis on anti-inflammatory foods, such as fruits, vegetables, whole grains, and olive oil, may help modulate the immune response and reduce systemic inflammation. These changes could potentially lead to an improvement in both the symptoms and overall progression of the disease (Saraux et al., 2016).

Systemic sclerosis

Systemic sclerosis (SSc), also known as scleroderma, is another autoimmune disorder characterized by the thickening and hardening of the skin and internal organs due to excessive collagen deposition (Denton & Khanna, 2017). SSc can lead to significant morbidity, particularly when internal organ involvement occurs in the lungs, heart, and kidneys. Raynaud's phenomenon, a condition where blood flow to the extremities is reduced due to spasm of blood vessels, is commonly observed in SSc and is one of the earliest signs of the disease (Denton & Khanna, 2017).

In the case of SSc, research on the effects of the Mediterranean Diet is still in its early stages, but several studies suggest positive outcomes. The MD's anti-inflammatory properties may improve patients' general mood and quality of life. A study found that individuals following the Mediterranean Diet had better mood scores, which could be beneficial for people with SSc, who often experience fatigue, depression, and anxiety as part of their disease (Dinu et al., 2018).

Additionally, patients with SSc who adhered more closely to the Mediterranean Diet showed a reduction in the frequency of Raynaud's phenomenon, a common and troubling symptom of the disease. However, it is important to note that while these improvements in mood and Raynaud's symptoms are promising, studies have not yet demonstrated significant changes in disease activity, as measured by clinical markers of inflammation or fibrosis progression (Stöcker et al., 2022).

Mechanisms of action

The potential benefits of the Mediterranean Diet in both Sjögren's syndrome and systemic sclerosis can largely be attributed to its anti-inflammatory and immunomodulatory effects. Key components of the diet, such as omega-3 fatty acids, polyphenols, and antioxidants, are thought to play a significant role in modulating immune responses and reducing inflammation. Omega-3s, for example, have been shown to reduce the production of inflammatory cytokines, which are central to the autoimmune processes in both pSS and SSc (Islam et al., 2020).

Olive oil, a hallmark of the Mediterranean Diet, contains phenolic compounds such as oleocanthal, which have been shown to possess anti-inflammatory properties similar to non-steroidal anti-inflammatory drugs (NSAIDs). These compounds can help to inhibit inflammatory enzymes and reduce oxidative stress, both of which are key contributors to the pathogenesis of autoimmune diseases like SSc and pSS (Islam et al., 2020).

In addition to the direct anti-inflammatory effects, the Mediterranean Diet is also rich in fiber, which supports gut health and may have further beneficial effects on the immune system. Research suggests that a healthy gut microbiome plays an important role in regulating immune function and may influence the development and progression of autoimmune diseases (Xu et al., 2019).

While the research on the Mediterranean Diet's effects in Sjögren's syndrome and systemic sclerosis is still in its infancy, current studies suggest that this dietary pattern may offer significant benefits for patients with these autoimmune diseases. The diet's anti-inflammatory, immunomodulatory, and antioxidant properties could help reduce disease activity, improve mood, and alleviate symptoms such as Raynaud’s phenomenon. More research is needed to fully understand the long-term effects of the Mediterranean Diet on disease progression, but the evidence so far points to its potential as a valuable adjunct to traditional treatments for these challenging conditions.

The role of the Mediterranean Diet in Hashimoto's thyroiditis

Hashimoto's thyroiditis is the most common autoimmune disorder of the thyroid, in which the body's immune system mistakenly attacks the thyroid gland, leading to its gradual destruction (Ruggeri et al., 2021). This condition results in hypothyroidism, a state where the thyroid gland is unable to produce sufficient thyroid hormones, which are crucial for regulating metabolism and overall body function. The management of Hashimoto’s thyroiditis typically includes thyroid hormone replacement therapy to compensate for the reduced hormone production. However, recent studies have suggested that dietary and lifestyle interventions, particularly adherence to the Mediterranean Diet, may play a significant role in managing the disease and improving patient outcomes (Ruggeri et al., 2023; Ruggeri et al., 2021).

Hashimoto's thyroiditis and the Mediterranean Diet: key findings

Several studies have investigated the effects of the Mediterranean Diet on Hashimoto’s thyroiditis, focusing on its potential to modulate disease activity and improve thyroid function (Ruggeri et al., 2023). The Mediterranean Diet is rich in fruits, vegetables, whole grains, legumes, nuts, seeds, and healthy fats, particularly extra virgin olive oil, which contains bioactive compounds with anti-inflammatory and antioxidant properties. Fish, particularly fatty fish rich in omega-3 fatty acids, is another key component of the diet, contributing to its anti-inflammatory effects.

One of the key findings from research on Hashimoto’s thyroiditis is the relationship between adherence to the Mediterranean Diet and thyroid autoantibody levels. Autoantibodies, such as anti-thyroid peroxidase (anti-TPO) and anti-thyroglobulin (anti-TG), are markers of autoimmune activity in Hashimoto's thyroiditis (Gąbka et al., 2023). Studies have shown that individuals who adhere less strictly to the Mediterranean Diet tend to have higher levels of these autoantibodies, suggesting that poor diet quality may exacerbate autoimmune activity. Conversely, greater adherence to the Mediterranean Diet appears to have a protective effect, with lower levels of thyroid autoantibodies observed in patients who closely follow the dietary guidelines (Bellastella et al., 2022).

Mechanisms of action: how the mediterranean diet supports thyroid health

The beneficial effects of the Mediterranean Diet in Hashimoto’s thyroiditis can be attributed to several factors. First and foremost, the diet's high content of antioxidants and anti-inflammatory compounds plays a crucial role in modulating immune responses (Ruggeri et al., 2023). The Mediterranean Diet is rich in polyphenols, particularly those found in olive oil, which

have been shown to reduce oxidative stress and inflammation—both of which are key contributors to autoimmune processes. Chronic inflammation is known to exacerbate the progression of autoimmune diseases, including Hashimoto's thyroiditis, so reducing this inflammation may help protect thyroid tissue from further damage (Wrońska et al., 2024).

Furthermore, the Mediterranean Diet emphasizes the consumption of omega-3 fatty acids, primarily from fish, which are known for their potent anti-inflammatory properties. Omega-3 fatty acids inhibit the production of pro-inflammatory cytokines, which are involved in the immune-mediated damage seen in Hashimoto's thyroiditis. By reducing inflammation, omega-3s may help mitigate the autoimmune attack on the thyroid gland and improve thyroid function (Sobek et al., 2024).

The diet also promotes the intake of foods that support gut health, including fiber-rich fruits, vegetables, and whole grains. The gut microbiome plays a significant role in regulating immune function, and dysbiosis (an imbalance in gut bacteria) has been implicated in the development and progression of autoimmune diseases, including Hashimoto's thyroiditis. By promoting a healthy gut microbiome, the Mediterranean Diet may help modulate immune responses and reduce the risk of autoimmune flare-ups.

Impact on thyroid function and disease activity

In addition to its effects on autoimmune markers, adherence to the Mediterranean Diet has been shown to improve thyroid function in some patients with Hashimoto's thyroiditis. Specifically, the diet may help optimize the levels of thyroid hormones (T3 and T4) and reduce symptoms associated with hypothyroidism, such as fatigue, weight gain, and depression. This is particularly important for patients who are managing their thyroid condition with hormone replacement therapy, as the diet may complement medication and enhance its effectiveness.

Moreover, the anti-inflammatory and antioxidant properties of the Mediterranean Diet may help reduce the overall disease activity in Hashimoto's thyroiditis, potentially slowing disease progression. By reducing inflammation and promoting thyroid health, the diet can help manage symptoms more effectively and improve the patient's quality of life (Sobek et al., 2024; Wrońska et al., 2024).

Clinical evidence and future directions

While the clinical evidence regarding the Mediterranean Diet's effects on Hashimoto's thyroiditis is still emerging, early studies suggest that this dietary pattern may be a valuable adjunct to traditional treatment approaches. Adhering to a Mediterranean-style diet may help modulate autoimmune activity, reduce thyroid autoantibodies, and support thyroid function. However, more long-term studies and randomized controlled trials are needed to fully understand the mechanisms through which the Mediterranean Diet influences Hashimoto's thyroiditis and to confirm its role in disease (Kallai et al., 2025; Sobek et al., 2024; Ungvari et al., 2025; Wrońska et al., 2024).

The Mediterranean Diet represents a promising dietary approach for individuals with Hashimoto's thyroiditis. Its combination of anti-inflammatory, antioxidant, and immune-modulating properties may help reduce disease activity, improve thyroid function, and support overall well-being. By emphasizing nutrient-dense foods such as fruits, vegetables, fish, and olive oil, the Mediterranean Diet can complement conventional treatment and provide a holistic strategy for managing autoimmune thyroid diseases. While further research is needed to solidify its role in the treatment of Hashimoto's thyroiditis, the Mediterranean Diet offers a scientifically supported, cost-effective, and sustainable option for improving the health of individuals with this condition (Sobek et al., 2024; Wrońska et al., 2024).

CONCLUSION

The Mediterranean Diet presents a promising adjunctive treatment option for patients dealing with autoimmune diseases, as it has the potential to reduce disease activity, improve autoimmune outcomes, and promote weight loss. The beneficial effects of the diet are primarily

attributed to its ability to strengthen the immune system, support the gut microbiota, and reduce inflammation. Although further research is needed to fully understand the exact mechanisms through which the Mediterranean Diet influences autoimmune diseases, the existing evidence is encouraging. Encouraging the Mediterranean Diet as part of treatment offers a cost-effective solution that involves lifestyle changes and could significantly aid in the management of autoimmune conditions.

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AN EVENT-BASED TRAFFIC MANAGEMENT APPLICATION IN VANETS

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Abstract
Vehicular Ad Hoc Networks (VANETs), an important sub-branch of intelligent transportation systems (ITS), have become quite interesting in both academia and industry in recent years. Thanks to the wireless communication between vehicles and roadside units, important traffic-related information is shared in VANETs, and thus, safety, management and infotainment applications can be implemented. In VANET event-based traffic management systems, vehicles that witness an event on the route broadcast an event status message to their neighbors in order to warn them. The vehicles receiving this message wait for a decision until their distance to the event falls below a certain threshold and make a one-time decision depending on the messages they receive. With the decision made, it is aimed for the vehicles to take precautions without having to witness the event, thus preventing traffic congestion and reaching their destinations earlier. In this study, an accident event is created at the midpoint of three consecutive roads on a 3-road urban scenario using the simulation method, and the vehicles that witnessed the accident are made to stop and broadcast an incident report around them. In this way, it is aimed for the vehicles that have not witnessed the incident to take early precautions by changing their routes to prevent waiting due to traffic congestion. The performance of the proposed traffic management system with messaging content is compared with the classical traffic scenario without messaging, in terms of the time for the vehicles to reach the destination, the number of vehicles that stop during journey, and their stopping times. The simulation results indicated that the event-based communication system avoids route congestion by enabling timely route changes for vehicles, distributing traffic to alternative routes, decreasing the number of halted vehicles in the network, and reducing the time needed for vehicles to arrive at their destinations. It is thought that the obtained results will shed light on future event-based traffic management scenarios and trust-based communication systems.
Keywords: traffic management, event messaging, simulation, VANET.

1. INTRODUCTION

The increasing number of vehicles on the global scale has led to the need for new solutions related to traffic management. This progress has led to the emergence of applications based on interaction between vehicles. Owing to the services of VANET systems, which include communication between vehicles and roadside units, many applications such as collision detection, congestion management, security, traffic monitoring, etc. can be implemented in both urban and highway traffic scenarios [1,2]. However, when vehicle communication is taken into account, the process of reporting incidents in traffic is both inefficient and slow today [3]. Therefore, in recent years, the subject of providing traffic management using VANET has become quite popular in the literature [1-10].

Brandao et.al (2020) [3], drawing attention to the negative effects of accidents occurring in urban traffic scenarios, proposed the detection of accidents and the dissemination of warning messages in the network over multiple hops in order to reduce congestion. Using the simulation method, it is proven that their algorithm is better than PANDORA and NRR solutions in terms of vehicle travel time, lost time and number of messages transmitted.

Kaur et.al (2020) [4] proposed an infrastructure that enables the detection of traffic accidents and the prioritization of emergency vehicles so that ambulances can reach their destinations on time. In another study [5], the authors stated that many users today use Google Maps and GPS to prevent problems such as traffic congestion, but they only reach the destination via the shortest route. It is not possible to monitor instant events through these applications. In their study, alternative routes are created by evaluating the context information of events and environmental conditions.

In another study in which the accidents are detected and traffic congestion is prevented [6], secure transmission of traffic information is provided by using machine learning methods. Kaur and Verma [7], who emphasized that there is not enough study in the literature on the dissemination of emergency information after an accident/incident in VANETs, proposed a routing algorithm to prevent congestion. Duarte et. al. [8] offer both the prevention of accidents and the effective management of traffic lights with the communication established between emergency vehicles and traffic lights. Radi et.al [9] suggest another traffic accident management system, processes data from real-time traffic via cameras and sensors using machine learning methods and takes action according to the results obtained (e.g., notifying the police station, calling an ambulance, etc.). Yordanova and Haka [10] have developed a framework that allows responding to and managing incidents that may occur in traffic using blockchain together with fog and cloud computing methods.

In this study, it is aimed to prevent traffic congestion by broadcasting the emergency status message among the vehicles using VANET V2V communication against an event occurring in urban traffic and by selecting an alternative route for the vehicles receiving the message. By delaying the broadcast time of the message in certain cases and spreading the messages about the end of the incident in the network for a while, the waiting times in traffic are optimized. The proposed algorithm, modeled with the simulation method, has shortened the time for vehicles to reach their destinations compared to the current traffic system where communication is not used and has prevented congestion by reducing the stopping times in traffic.

2. SYSTEM ARCHITECTURE

In this study, an urban traffic scenario is modeled by using OMNeT++, SUMO and Veins. The scenario consists of 3 main roads, each with 2 lanes, and 4 single-lane and one-way secondary roads connecting consecutive main roads, as seen in **Figure 1**.

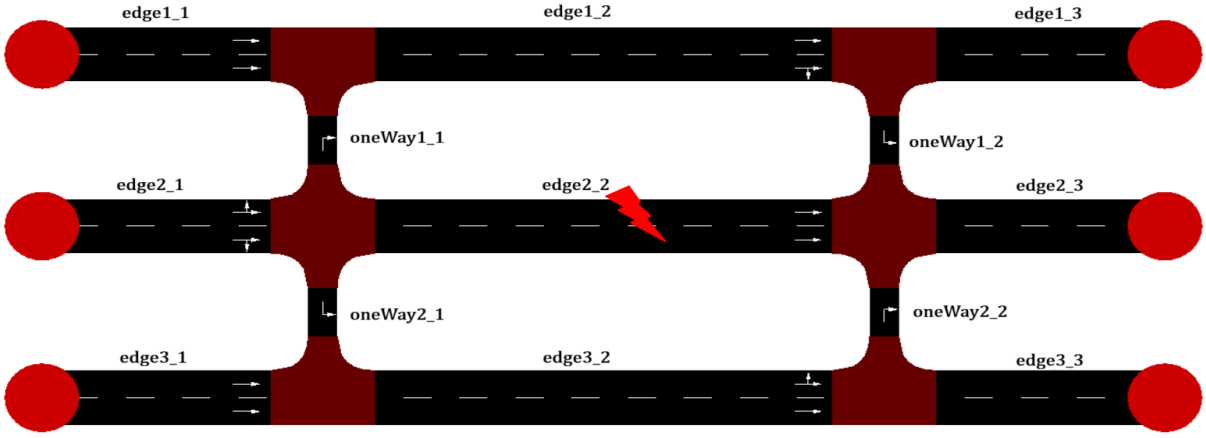

Figure 1. The urban traffic scenario used in this study

In default mode (i.e. without any traffic event), there are three vehicle flows on different routes including Route 1, Route 2 and Route 3. The roads (i.e. edges) in each route is shown in **Table 1**. As is seen in **Table 1**, since no roads on the routes overlap, vehicles can travel to their destinations without hindering each other.

Table 1. Routes in default mode

Route	**List of Roads**
Route 1	edge1_1 - edge1_2 - edge1_3
Route 2	edge2_1 - edge2_2 - edge2_3
Route 3	edge3_1 - edge3_2 - edge3_3

As seen in **Figure 1**, an event is created on the road of "***edge2_2***". The vehicles witnessing the event stop for the duration of the event. These vehicles broadcast a message informing the event to their neighboring nodes. Thus, the vehicles receiving this message can change their routes. Since the event is not located on their route, the vehicles traveling on Route 1 and Route 3 discard this message. However, the vehicles traveling on Route 2 search for an alternative route. There are 2 alternative routes in this network, one containing the 1st main road and the other containing the 3rd main road. Alternative routes are shown in **Table 2**. The vehicles choose one of the alternative routes with a 50% probability. While the route change reduces the waiting on Route 2, it will add additional load on Route 1 and Route 3. The aim of this study is to distribute the load on the network in a balanced way between the routes.

Table 2. Alternative routes for the vehicles on Route 2

Route	**List of Roads**
Alternative 1	edge2_1 - oneWay1_1 - edge1_2 - oneWay1_2 – edge2_3
Alternative 2	edge2_1 - oneWay1_1 - edge1_2 - oneWay1_2 – edge2_3

At the end of the event, the vehicles that witnessed the event and stopped broadcast the message "the event is over" to their surrounding nodes before moving. Thus, the vehicles that changed their route can return to their old route. In this way, the load on Route 1 and Route 3 are reduced and the network becomes balanced.

In order to evaluate the performance of the proposed V2V communication system, five different scenarios (i.e. states) are modeled. For each scenario, performance evaluation is conducted according to the waiting times of the vehicles in the network and the time they took to reach their destination.

State 1: In this state, there is no event in the network. The upper limit of the performance of the system can be observed in this scenario.

State 2: The event is created in this state. However, there is no communication between the vehicles. This situation, which is seen in real-life traditional traffic models, is measured to evaluate the base performance values on the system.

State 3: The event is also created in this state. The vehicles broadcast the existence of the event when they receive the event message. The vehicles send this message as soon as they witness the event.

State 4: This state is similar to State 3. However, broadcasting process of the event message is postponed to road changing. The purpose of this scenario is to ensure that more vehicles change their routes.

State 5: In addition to State 4, this state includes the addition of the "no event" message. It ensures that the vehicles return to their old routes when the event ends.

3. RESULTS AND DISCUSSION

Initially, the state of the system before the event (State 1) is examined and the highest performance level obtained from the network is reported. The number of vehicles traveling on three different routes, average travel lasting time and the waiting/stopping time in the network are measured (**Table 3**). It can easily be said that 34 vehicles traveled on each route and their average travel times are close to each other. No vehicle waited in the network during its journey.

Table 3. The performance of the network for State 1

	Route 1	**Route 2**	**Route 3**
Vehicle Number	34	34	34
Average Travel Lasting Time	195,29	193,5	196,02
Waiting Time	0	0	0

After simulating State 1, an event is added to the system on **edge2_2**, which occurred at the **50**th second of the simulation and continued for **120** seconds, with a coverage area of **50** meters. The vehicles witnessing the event stop until the event ends. There is no communication in this scenario. Therefore, since the vehicles do not change their route, no difference is observed on Route 1 and Route 3. However, the vehicles accumulated on Route 2 over time. The effects of State 1 on Route 2 are shown in **Table 4**. All vehicles traveling on Route 2 stopped for at least **11** seconds and at most **116** seconds. The total waiting time of the vehicles is **2193** seconds. The travel lasting times of the vehicles increased by an average of **68** seconds compared to the previous scenario.

Table 4. The performance of the vehicles on Route 2 for State 2

Performance Parameters	**Values for Route 2**
Total waiting time	2193
# of waiting vehicles	34
Minimum waiting time	11
Maximum waiting time	116
Average waiting time	64,5
# of vehicles with longer travel	34
Maximum delay	118
Minimum delay	17
Average delay	68,02941
Average Travel Lasting Time	261,5294

The travelling and waiting times of the vehicles on Route 2 are shown in Figure 2a and Figure 2b, respectively. As is seen in Figure 2, both the waiting times and the total travel times of all vehicles on Route 2 have been extended due to the event.

In order to reduce congestion on Route 2 and distribute the load to other routes, a communication mechanism between vehicles is added to the system. Vehicles that witness the event broadcast the "event" message to their surrounding nodes. The nodes receiving this message initially change their routes and then continue to spread the event message to their neighbors in the network, immediately. In this way, the message spreads quickly in the network. The point to be noted here is that vehicles do not enter the system all at once, but rather sequentially over time. Therefore, vehicles that are not in the network at the time the message is spread / vehicles that enter late cannot hear this event message. This causes the number of vehicles affected by the message to be limited. As a result of the simulations performed, the changes on Route 1, Route 2 and Route 3 are measured. First of all, the results related to the vehicles that changed routes are shown in **Table 5**. Although 34 vehicles traveled on Route 2 during the network lifetime, only 7 vehicles changed routes by receiving the event message. Vehicles that changed routes do not wait at all in the network. The average travel times have also decreased compared to the previous scenario (State 2 as seen in Table 4). In this case, it is clearly be observed that it is advantageous for the vehicles to change their route.

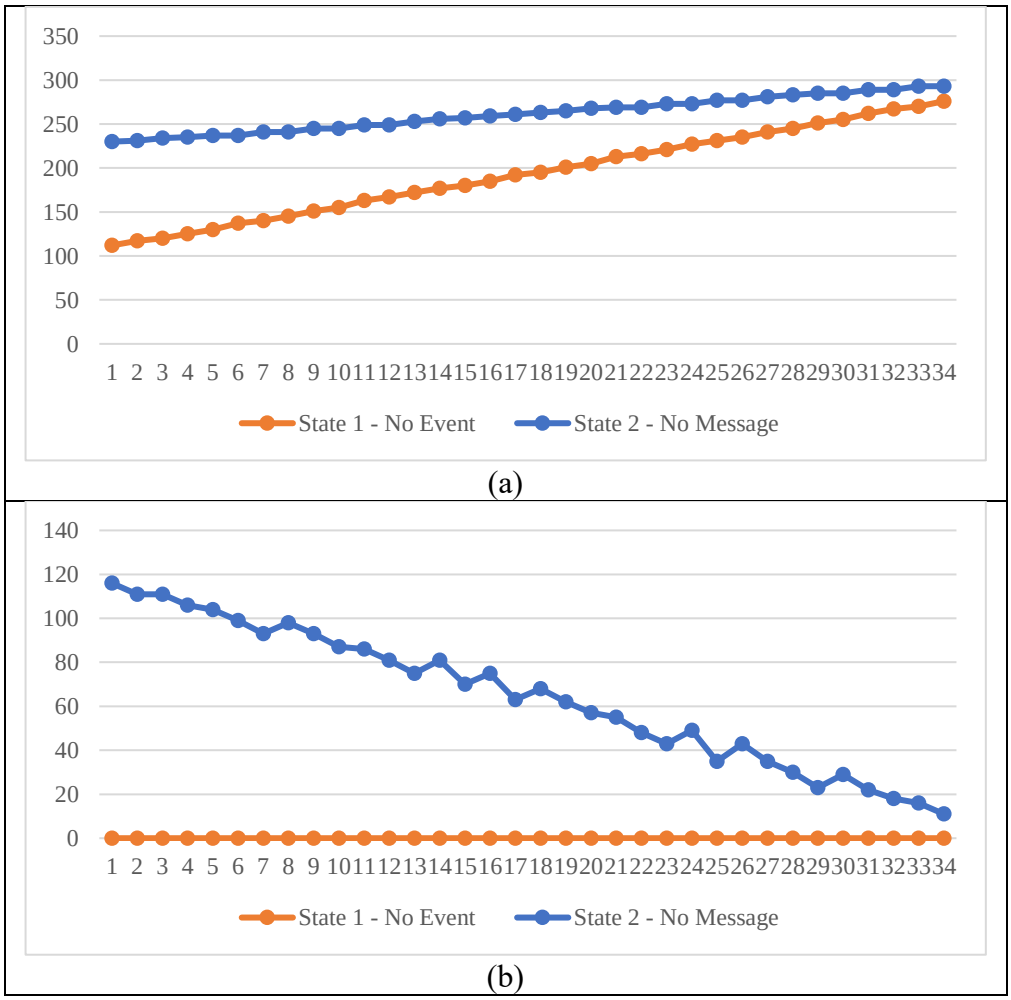

Figure 2. Travel (a) and waiting (b) time of vehicles on Route 2 for State 1 and State 2

Table 5. The performance of the vehicles changing their routes for State 3

Vehicles changing routes	Value
Vehicle Number	7
Average Travel Lasting Time	249
Waiting Time	0

It is expected that the vehicles changing routes will have a negative impact on the vehicles traveling on other routes due to the additional traffic. The fact that this impact is lower than the waiting times on Route 2 in the previous scenario will indicate that the total performance of the network has increased. The reflection of the route change process on the vehicles on Route 1 and Route 3 is evaluated in **Table 6**. As expected, there was a slight increase in the travel times of the vehicles and have also been some delays and waits. However, the performance decreases obtained are insignificant compared to State 1.

Table 6. The performance of the vehicles on Route 1 and Route 3 for State 3

	Route 1	Route 3
Total waiting time	35	75
# of waiting vehicles	6	7
Minimum waiting time	1	1
Maximum waiting time	12	20
Average waiting time	5,83	10,71
# of vehicles with longer travel	10	15
Maximum delay	16	21
Minimum delay	2	1
Average delay	5,7	6,7
Average Travel Lasting Time	196,7	198,7

The change in the waiting status of the vehicles in the network is observed the most on Route 2 (**Figure 3**). As a result of 7 vehicles leaving the route, their waiting time became 0. However, the waiting time of the vast majority of vehicles decreased. Only the waiting time of the last few vehicles increased. This shows that the congestion on Route 2 is diminished and vehicles wait less in the event of messaging.

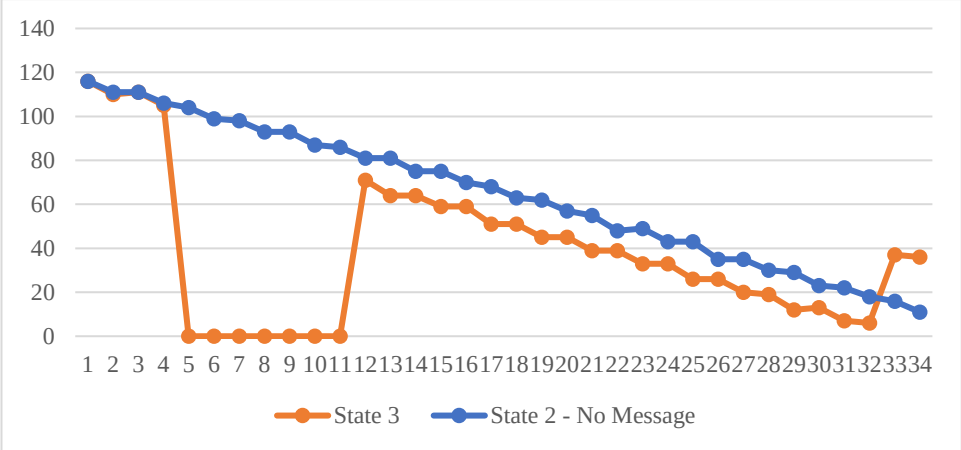

Figure 3. Waiting time of vehicles on Route 2 for State 2 and State 3

The limitation of the number of vehicles changing routes to 7 in State 3 is due to the fact that the event message is immediately sent by the vehicles and the vehicles that have just entered the

network cannot receive this message. In order to improve the performance of the system, the vehicles wait for their messages until the moment of changing routes (State 4). The effect of this waiting process on the system performance is measured. Although the change of routes by more vehicles creates more additional load on Route 1 and Route 3, the effect of these loads on both the waiting times of the vehicles and the total travel times remains low compared to State 1 (**Table 7**).

When the status of the vehicles changing route in State 4 is examined (**Table 8**), it is observed that 30 vehicles changed route without waiting in the network. The change in the waiting time of these vehicles compared to State 2 can be observed in more detail in **Figure 4**.

Table 7. The performance of the vehicles on Route 1 and Route 3 for State 4

	Route 1	**Route 3**
Total waiting time	89	490
# of waiting vehicles	11	20
Minimum waiting time	1	1
Maximum waiting time	27	69
Average waiting time	8,09	14,41
# of vehicles with longer travel	17	20
Maximum delay	31	119
Minimum delay	1	19
Average delay	6,88	75,65
Average Travel Lasting Time	198,64	240,44

Table 8. The performance of the vehicles changing their routes for State 4

Vehicles changing routes	**Value**
Vehicle Number	30
Average Travel Lasting Time	207
Waiting Time	0

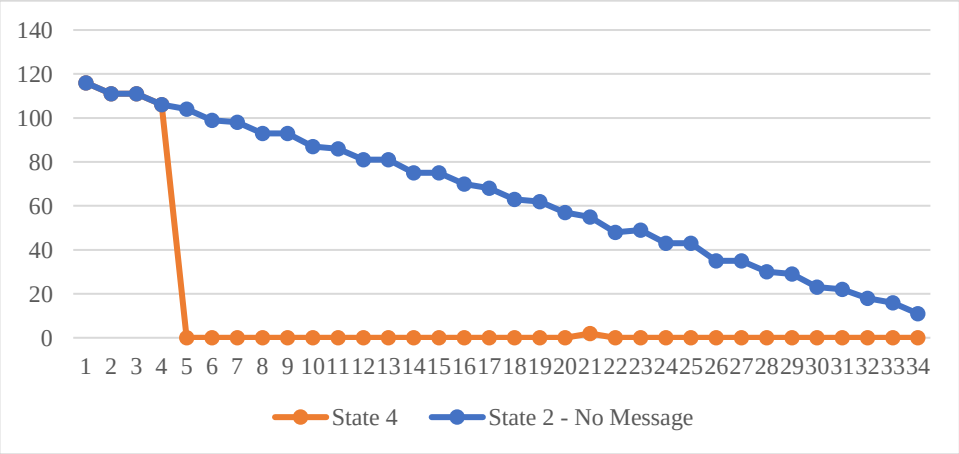

Figure 4. Waiting time of vehicles on Route 2 for State 2 and State 4

Finally, in the modeled State 5, when the event is over, the vehicles witnessing the incident send a message warning "the incident is over" so that the vehicles would not change their routes any further and would not create additional load on Routes 1 and 3 by continuing on their old routes. State 5 is compared with State 4 and **Table 9** shows this comparison evaluation. There is no change in the routes of a total of 70 vehicles, their network stop/wait times and total travel

times. 23 vehicles continued on the same route but their travel times are shortened. 12 vehicles continued on their old routes. Both waiting and travel times are shortened. Therefore, declaring the ending of the event and ensuring that the vehicles remained on their old routes enabled the vehicles to reach their destination in a 31% shorter time.

Table 9. Changes in State 5 compared to State 4

# of Vehicles	Route Change	Wait Time Change	Travel Time Change
70	No	No	No
20	No	No	Decrease
12	Yes	Decrease	Decrease

4. CONCLUSION

VANET enables traffic management in smart cities, allowing both security and the use of infotainment applications. After important information is rapidly disseminated on the network thanks to communication between vehicles, accidents, blockages, etc. can be prevented by taking the necessary precautions. In this study, the congestion created by an event in urban traffic is shown, and then vehicles are directed to alternative routes by using VANET V2V communications, thus optimizing travel time.

The results obtained from the simulations showed that the event-based communication system prevents congestion on a route by allowing vehicles to change routes on time, by distributing the load to other routes, by reducing the number of vehicles stopped in the network and by shortening the time for vehicles to reach their destination. In addition to spreading messages about the occurrence of the event, it is also ensured that the vehicles remain on their old routes by broadcasting messages about its completion, thus reducing the additional load on other routes. By keeping the messages about the event until the route change, the vehicles that newly join the network are also informed about the event and more vehicles are able to take precautions. In future studies, the communication algorithm will be tested in multiple events and different traffic scenarios and updated adaptively according to the environmental conditions.

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MEDICAL RESPONSIBILITY IN THE DIGITAL AGE

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SUMMARY
The emergence of innovative health technologies, such as telemedicine, connected devices, and artificial intelligence, improves access to care and assists healthcare professionals. However, their use raises ethical and legal questions, particularly regarding medical responsibility in the event of an error. It is crucial to determine who is responsible when damage occurs: the doctor, the software manufacturer, or the healthcare institution. Indeed, the consideration of the legal and ethical issues related to digital tools in health requires an analysis of medical responsibility and AI.
Keywords: New technology in healthcare, telemedicine, AI, medical liability, fault liability no-fault liability, defective product.

LA RESPONSABILITÉ MÉDICALE À L'ÈRE DU NUMÉRIQUE

RÉSUMÉ
L'émergence des technologies innovantes en santé, comme la télémédecine, les objets connectés et l'intelligence artificielle, améliore l'accès aux soins et assiste les professionnels de santé. Cependant, leur utilisation soulève des questions éthiques et juridiques, notamment sur la responsabilité médicale en cas d'erreur. Il est crucial de déterminer qui est responsable lorsqu'un dommage survient : le médecin, le fabricant de logiciel ou l'établissement de santé. En effet, La réflexion sur les enjeux juridiques et éthiques liés aux outils numériques en santé nécessite une analyse de la responsabilité médicale et de l'IA.
Mots-clés: Nouvelle technologie en santé, télémédecine, l'IA, la responsabilité médicale, responsabilité pour faute la responsabilité sans faute, produit défectueux.

INTRODUCTION

L'essor des technologies innovantes en santé, comme la télémédecine et l'intelligence artificielle, améliore l'accès aux soins et assiste les professionnels de santé. Cependant, leur utilisation soulève des questions éthiques et juridiques, notamment en matière de responsabilité médicale. Cette dernière, bien qu'étant une forme de responsabilité civile, se concentre sur le domaine délicat de la santé et vise à indemniser les victimes de préjudices causés par des professionnels de santé. La responsabilité légale liée aux soins numériques interpelle sur l'identification des risques et l'application de règles juridiques. En cas d'erreur liée à ces technologies, la question cruciale demeure : qui est responsable, médecin, fabricant ou établissement de santé ?

En effet, La réflexion sur les enjeux juridiques et éthiques liés aux outils numériques en santé nécessite une analyse de la responsabilité médicale**(I)** et de l'IA **(II).**

RESEARCH AND FINDINGS

I -la responsabilité médicale liée à la télémédecine

La responsabilité impose à une personne de rendre compte de ses actions selon son rôle et ses obligations, entraînant des conséquences possibles, sanctions ou indemnisation selon la nature de la responsabilité évoquée.

En droit marocain, le médecin a une obligation de moyens[1]. La télémédecine peut entraîner des problèmes techniques ou médicaux, rendant les professionnels responsables et nécessitant une bonne information des patients.

1-La responsabilité médicale vis à vis à la réalisation de l'acte de la télémédecine

La doctrine discute des responsabilités en télémédecine. Monsieur OLIVIER Jardé souligne que les règles de responsabilité des professionnels de santé en télémédecine sont identiques à celles de la médecine traditionnelle, reposant sur le droit commun.La responsabilité du médecin en téléconsultation est similaire à celle d'une consultation classique[2], mais nécessite une attention particulière sur la prise de décision, le consentement et l'information du patient, qui doit être plus complète concernant la prise en charge[3].

En effet, La responsabilité des actes de télémédecine concerne tous les professionnels de santé, sans dérogation au droit commun, et se divise en responsabilité civile en milieu privé et responsabilité administrative en milieu hospitalier.

1-1 La responsabilité sanction

La responsabilité pénale et disciplinaire des médecins en télémédecine exige le respect du secret médical, conformément aux lois marocaines et françaises. Au Maroc, l'article 11 du code de déontologie et l'article 446 du code pénal protègent les informations des patients. En France, l'article 223-1 engage la responsabilité des professionnels en cas de négligence avec des dispositifs médicaux numériques**,** mettant ainsi en danger la vie d'un patient[4].

Cependant, La responsabilité disciplinaire en télémédecine exige des conditions strictes pour garantir la qualité des soins, les médecins doivent exercer légalement, avec une responsabilité semblable à celle des consultations traditionnelles[5],et ce même si elle s'opère par voie électronique[6]**.**Les médecins doivent respecter les mêmes obligations déontologiques que

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[1] Article 78 du DOC Marocain.

[2] Le décret du 3 juin 2021, introduit l'article R.6316-2 dans le Code de la santé publique française qui dispose que *: « La pertinence du recours à la télémédecine ou au télé soin est appréciée par le professionnel médical, le pharmacien ou l'auxiliaire médical ».*

[3] Aux dispositions de l'article L 1111-2 du Code de la santé publique française, s'ajoutera l'information portant sur le dispositif de télémédecine utilisé.
-Article. R 6316-2 Code de la santé publique française

[4] L'atteinte su droit de la personne résultant des fichiers ou de traitement informatique en violation des articles 226-16 à 226-24 du code pénal français.

[5] Livre blanc sur la télémédecine en France. 2009.

[6] V. H. SIMONIAN-GINESTE, Les professions (dé)réglementées : Bilans et perspectives juridiques, Presses de l'Université Toulouse 1 Capitole, 19 sept. 2019, P. 236.

lors des consultations traditionnelles, malgré la nature électronique de la télémédecine, sous peine de sanctions administratives[7].

1-2 La responsabilité indemnitaire

Cette responsabilité indemnitaire comprend, la responsabilité administrative et la responsabilité civile. La responsabilité indemnitaire en télémédecine inclut la responsabilité administrative, qui exige l'authentification des professionnels [8], et l'identification du patient[9],et la responsabilité civile, où le médecin doit garantir la sécurité du patient et respecter les obligations contractuelles. Cette responsabilité demeure celle pour faute, permettant des poursuites individuelles ou conjointes pour les participants à l'acte de téléconsultation[10].

2-la responsabilité du professionnel de santé vis-à-vis aux outils technologiques utilisés en télémédecine

Les dispositifs de télémédecine, considérés comme des dispositifs médicaux, engagent la responsabilité des professionnels de santé en cas de panne. [11]. Ils doivent assurer la sécurité des résultats et respecter les exigences de conformité et de déclaration des incidents.

2-1 La responsabilité du médicale à l'égard l'utilisation d'outils technologiques

Les médecins doivent comprendre les technologies médicales et leurs limites, en sollicitant des spécialistes si nécessaire [12]. Ils portent la responsabilité légale même pour les dispositifs numériques.[13]. L'évaluation des compétences des tiers est essentielle, tout comme le respect du secret professionnel. La décision de téléconsultation revient au professionnel de santé, [14]. avec une responsabilité similaire dans la téléassistance [15].

2-2 La responsabilité des tiers technologiques

Les tiers technologiques doivent fournir un équipement fiable et sûr pour les opérations des TIC.[16]. En effet, dans le cadre d'une obligation renforcé[17], Les fournisseurs tiers assurent les outils de communication en santé. En cas de défaillance, les victimes peuvent poursuivre ces tiers, les clauses de non-responsabilité étant inapplicables.

II- La responsabilité médicale liée à l'utilisation de l'intelligence artificielle.

Le médecin doit déterminer s'il applique la responsabilité pour faute ou sans faute en cas de dommage lié aux outils numériques.

1- le maintien de la responsabilité pour faute

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[7] Laurène Mazeau, « Responsabilité », Cahiers Droit, Sciences & Technologies,2020 n°11.pp 227-234.en ligne : https://doi.org/10.4000/cdst.2968, consulté le 23/03/2025.

[8] Art 14 du Décret n° 2-18-378 du 11 kaada 1439 (25 juillet 2018) relatif à la télémédecine, bulletin officiel Nº 6696-19 kaada- 1439 publié le 2-8-2018.

[9] L. Mazeau, « responsabilité », Op.cit.

[10] CLUZEL-MÉTAYER Lucie & SÉE Arnaud (dir), Éléments De Droit Public Du Numérique, Marie Bastian, La construction du droit de la santé numérique, éd, L'Harmattan, Paris ,2023, P.100

[11] Article L.1142-1 du code de santé publique française.

[12] CONM, Télémédecine, la préconisation du conseil national de l'ordre des médecins, janvier 2009. P.12.

[13] Bénédicte Bévière -Boyer & Dorothée Dibie (dir), Numérique, droit et société, Dalloz 2022. P. 229.

[14]W. Djadouna ,S. Bart, Téléconsultation : cas clinique et cadre juridique, Progrès en Urologie - FMC Volume 32, numéro 1, mars 2022, pages F25-F31, disponible sur le site : https://doi.org/10.1016/j.fpurol.2021. 12.002, consulté le 12/04/2025.

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consulté le 12/04/2025.

[16]Art. L. 5211-1 et suivants / R. 5211-12 et suivants du code de santé publique française en matière de dispositifs médicaux.

[17] Art. R. 6316-9 du Code de santé publique française.

Depuis l'arrêt Mercier, l'obligation de soins des médecins est un devoir de moyen sans garantie de guérison [18]. La faute médicale demeure la base de la responsabilité, même avec l'IA.[19].

1-1-La faute liée à la décision de l'utilisation de l'IA

Les études sur l'IA en santé soulignent la responsabilité du personnel médical lorsqu'il utilise cette technologie pour les soins [20].L'IA doit soutenir les professionnels sans les remplacer. Il est essentiel que les juges évaluent la faute avec nuance, préservant la liberté du praticien pour le bien du patient.[21].

1-2- La faute liée au manque de l'obligation de l'information

Plusieurs fautes liées à l'utilisation de l'IA sont qui ont d'ordre technique s'ajoute, la faute d'information sur les risques liées aux actes de soins proposés[22].En effet le contenu de l'information ne cesse de s'élargir et progressivement étendu sous l'effet de la jurisprudence et la loi. L'IA pourrait obliger le juge à renforcer l'information du médecin sur les risques liés à son utilisation [23,]pouvant engager sa responsabilité même en tant que simple prescripteur.[24].

2-la responsabilité sans faute du fait du produits défectueux

Le législateur français établit une responsabilité objective pour les dommages causés par un produit de santé, mais identifie des complexités concernant le professionnel de santé impliqué**.**

2-1- la complexité de déterminer la responsabilité sans faute du fait du produit défectueux

Au Maroc, selon L'article premier de la **loi n° 84-12,** le produit de la santé comme le logiciel est considéré comme un dispositif médical [25]**,** En France le système de l'IA conçu à des fins diagnostic ou thérapeutique constitue donc un produit de la santé[26], La Cour de justice de l'Union européenne a jugé qu'un logiciel d'aide à la prescription est médical. [27]. La responsabilité sans faute s'applique si un produit de santé, comme un robot chirurgical, cause un préjudice au patient par son défaut[28], mais la question qui persiste concerne l'identification du professionnel de la santé en charge.

En France, la divergence entre la Cour de cassation et le Conseil d'État complique la responsabilité des dommages causés par l'IA, les victimes agissent contre utilisateur, puis utilisateur contre fabricant.

2-2 - Intelligence artificielle et aléa thérapeutique :

L'intelligence artificielle en santé ne garantira jamais une fiabilité totale, car la médecine reste une discipline souvent complexe face aux mystères humains[29]. Dans les situations médicales incertaines, l'indemnisation des victimes de l'IA doit refléter la solidarité nationale, comme pour d'autres interventions médicales, à la manière française.

CONCLUSION

L'intégration de nouvelles technologies en santé, comme la télémédecine et l'IA, remet en question la responsabilité médicale au Maroc, qui reste régie par des textes généraux et le code pénal. Cette situation exige une réforme du régime de responsabilité pour s'adapter aux

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[18] Alexandra BENSAMOUN &Grégoire LOISEAU (dir), droit de l'intelligence artificielle, éd, LGDJ, Lextenso, 2019, P.90
[19]*Ibid*. P.328
[20] *Ibid.* P.90
[21] *Ibid*. P.91
[22]Article.L.1111-2 du code de la santé publique française.
[23] Clémentine LEQUILLERIER, dossier thématique « L'impact de l'intelligence artificielle sur la relation de soin » JDSAM 2017, n°17.
[24] A. BENSAMOUN &G. LOISEAU, droit de l'intelligence artificielle, op.cit., P.91
[25] Article premier du loi 84-12 relative aux dispositifs médicaux.
[26]G. LOISEAU, JDSAM,2017, op.cit.
[27] de CJUE, 7 déc. 2017, n° C-329/16.
[28] A. BENSAMOUN &G. LOISEAU, droit de l'intelligence artificielle, op.cit., P.91
[29] A. BENSAMOUN &G. LOISEAU, droit de l'intelligence artificielle, op.cit., P.330

innovations, tout en préservant la protection des patients et des professionnels de santé pour garantir des soins de qualité.

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TRANSFORMATION ALGORITHM FOR SOLVING LINEAR ORDINARY DIFFERENTIAL EQUATION INTO INTEGRAL EQUATIONS USING BOUBAKAR POLYNOMIALS

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ABSTRACT

In this research, we use computer algorithms to solve second-order initial value problems (IVPs) involving linear ordinary differential equations, using Boubakar polynomials as the main functions. Also, standard and Chebyshev-Gauss-Lobatto collocation points were respectively used to collocate the approximate solution. The ODEs were first converted to integral equations, and the basis function was substituted to obtain a set of linear algebraic equations, which then formed equations that were solved through the Maple software package. Numerical examples were provided to demonstrate the method's performance for various orders, as well as comparisons with exact and approximate solutions for various orders. However, it was observed that as the degree of approximation N increased, the results were very close to the exact solution, as can be seen from the tables of errors and graphical presentations.

Keywords: Boubakar polynomials, Chebyshev-Gauss-Lobatto collocation points, Standard collocation points, Initial value problem, Integral equations

1. INTRODUCTION

In recent years it has turned out that many phenomena in fluid mechanics, visco-elasticity, biology, physics, engineering and other areas of science can be successfully modeled by the use of derivatives and integrals. Several analytical and numerical methods have been proposed to solve ordinary differential equations, integral equations and integro-differential equations of physical interest. The most commonly used ones are: Adomian Decomposition method (ADM) (Wazwaz, 2015), Variational iteration method (VIM) (Wazwaz, 2011), Least square Chebyshev method by Oyedepo, Ayinde, Ishaq and Adenipekun (2021), Hybrid method by Kwami, Okai, Adamu, Waziri, Baba and Ayinde, (2021) and so on. Ordinary differential equations are ubiquitous in science and engineering: in geometry and mechanics, in chemical re-action kinetics, molecular dynamics, electronic circuits, population dynamics and many more application areas. They also arise after discretization in space, in the numerical treatment of time-dependent partial differential equations which are even more impressively omnipresent in our technological developed and financially controlled world.

Boubaker polynomials, introduced by Karem Boubaker in 2004, have emerged as a promising tool for obtaining approximate solutions to higher-order ordinary differential equations (ODEs). While not as widely recognized as established methods, Boubaker polynomials offer an alternative approach with potential advantages in specific contexts. This comprehensive review explores the contributions of various researchers who have advanced the understanding and application of Boubaker polynomials in solving higher-order ODEs. The foundation for Boubaker polynomials was laid by Karem Boubaker in his work aimed at solving a one-dimensional heat transfer equation. The resulting polynomials, though not explicitly named at that time, exhibited unique properties that made them suitable for approximation techniques. Boubaker's initial approach focused on second-order linear differential equations, demonstrating the effectiveness of the polynomials in obtaining approximate solution.

Higher-order ordinary differential equations (ODEs) play a crucial role in various scientific and engineering fields, describing phenomena ranging from motion dynamics to heat transfer and wave propagation. However, solving these equations analytically can be challenging, especially for non-linear cases. This limitation motivates the exploration of alternative solution approaches such as transforming them into integral equations.

Numerical methods play a crucial role in solving integral equations, particularly in the context of linear Volterra and Fredholm integral equations. These equations have wide applications in various scientific and engineering fields, including physics, biology, finance, and signal processing. Developing efficient and accurate numerical techniques for solving such equations is of great importance in tackling real-world problems. Researchers have explored the use of collocation methods for solving linear Volterra and Fredholm integral equations. Collocation methods involve selecting specific points, known as collocation points, within the domain of the integral equation and constructing an approximation based on these points. The choice of appropriate collocation points is crucial to ensure accurate solutions. One promising approach in this regard is the utilization of Boubaker Polynomial method as a basis for collocation methods. Boubaker's method is a relatively recent approach for transforming higher-order ODEs into Volterra integral equations of the second kind. It offers an alternative to classical methods like Laplace transforms or Green's functions.

In recent years, Volterra integral equations have become increasingly important in physics and engineering, with applications ranging from potential theory and electrostatics to particle transport in astrophysics, reactor theory, contact mechanics, diffusion processes, and heat transfer. These equations typically take the form

$$\delta(t) = f(t) + \int_{\alpha(t)}^{\beta(t)} k(t,s)\delta(s)ds \quad (1)$$

$\alpha\ (t)$ and $\beta(t)$ are function in t and $k(t,s)$ represents the kernel function. Similarly, Fredholm integral equations play a crucial role in various scientific domains, offering powerful mathematical tools for modeling complex phenomena across multiple disciplines.

Several recent studies have focused on the application of numerical collocation points and Boubaker polynomials for solving linear Volterra and Fredholm integral equations. These studies have proposed novel algorithms and numerical techniques, aiming to improve the efficiency and accuracy of the solution process. By incorporating the specific properties of Boubaker polynomials, these methods provide robust and reliable solutions to integral equations.

Prominent scholars have made various attempts to address higher-order initial value problems, focusing particularly on special second-order ordinary differential equations through diverse methods. Lambert (1973), Enright (1974), Jeltsch (1976), Brown (1974, 1977), Wanner (1978), Jeltsch et al. (1978), and Twizell and Khaliq (1981, 1984) each independently introduced a method known as the Multiderivative Method for solving second-order initial value problems. They found that Multiderivative methods not only provide high accuracy but also exhibit good stability properties for solving first-order initial value problems. In 1984, Twizell and Khaliq (1984) proposed a class of P-stable two-step higher derivative formulas specifically for special second-order initial value problems using the Pade approximation technique.

Their work showcased the potential of Boubaker polynomials in handling more complex ODEs. Kumar (2006) applied Boubaker polynomials to solve Love's equation, which arises in various physical contexts like the theory of elasticity. This application demonstrated the versatility of Boubaker polynomials in different scientific disciplines. Kharche (2006) established recurrence relations for Boubaker polynomials, providing a more efficient way to compute them. This mathematical advancement facilitated the practical application of Boubaker polynomials for solving higher-order ODEs. El-Aziz (2005) conducted detailed analyses of the convergence properties of Boubaker polynomial series. Understanding convergence is essential for determining the accuracy and reliability of the approximate solutions obtained using these polynomials.

The excellent work conducted by the aforementioned researchers inspired us and ultimately led to the use of numerical collocation points for solving linear ordinary differential equations using Boubakar Polynomials

2. BASIC DEFINITION

Definition 2.1

Ordinary differential equations (ODEs)

An ordinary differential equation (ODE) is an equation that relates a function $\delta(p)$ to some of its derivatives $\delta^n(p) = \frac{d^n\delta}{dp^n}$. It is usual to call x the independent variable and y the independent variable. The most general nth order linear differential equation can be written as

$$a_0(p)\frac{d^n\delta}{dp^n} + a_1(p)\frac{d^{n-1}\delta}{dp^{n-1}} + \cdots + a_{n-1}(p)\frac{d\delta}{dp} + a_n\delta = f(p) \quad (2)$$

With $a_0(p) \neq 0$ and is defined over some interval$a \leq p \leq b$.The functions $a_0(p), a_1(p), \ldots, a_n(p)$, are called the coefficients of the equation and the known function $f(x)$ is called the non-homogeneous term.

Definition 2.2

Integral equations (Wazwaz, 2011)

An integral equation is the equation in which the unknown functions $U(x)$ appears inside an integral sing. The most standard type of integral equation in $U(x)$ is of the form.

$$\delta(p) = f(p) + \lambda\int_{g(p)}^{h(p)} k(p,t)\delta(t)dt \quad (3)$$

Where $g(p)$ and $f(p)$ are the limits of integration, λ is a constant parameter and $k(p,t)$ is known function of two variables p and t called the kernel or the nucleus of the integral equations.

Definition 2.3

Fredholm Integral equation:

The standard form of Fredholm integral equations, where the limits of integration a and b are constants, are given by the form

$$\varphi(p)\delta(p) = f(p) + \lambda\int_a^b k(p,t)\delta(t), \quad (4)$$

Definition 2.4

Volterra Integral equation

The Volterra integral equation contains the unknown function $\delta(p)$ which appears outside the integral sign. The upper limits of integration in this case are variable. The Volterra integral equation appears in the form

$$\varphi(p)\delta(p) = f(p) + \lambda\int_0^p k(p,t)\delta(t) \quad (5)$$

Definition 2.5

***Collocation method** (Ayinde et al. 2021)*

Collocation method is a method that involves evaluation of approximate solution in a suitable set of functions called basis function or trial solution.

Definition 2.6

Standard collocation method (Agbolade and Anake, 2017)

The method is used to determine the desired collocation points within an interval $[a,b]$ and is given by $p_i = a + \frac{(b-a)i}{N}, i = 1, 2, \ldots$ (6)

Definition 2.7

Chebyshev Gauss-Lobatto collocation points **(Boyd, 2013)**

$$p_k = \cos\left(\frac{\pi k}{N}\right), \quad k = 0, 1, 2, \cdots, N \quad (7)$$

These collocation points will help us investigate the efficiency, accuracy, and the amount of work done in carrying out the numerical technique for the solution of the linear ODEs to be considered.

Definition *2.8*

Exact solution

A solution is called exact solution if it can be expressed in a closed-form such as a polynomial, exponential function, trigonometric function, or the combination of two or more of these elementary functions.

Definition 2.9

Approximate solution

An approximate solution is an exact representation of the exact solution that is still close enough to be useful. In this research the approximate solution is given as

$$\delta_N(p) = \sum_{k=0}^{N} a_k H_k(p) \quad (8)$$

where $a_k, k = 1,2,\ldots M$ unknown constant to be determined are, $H_k(x)(k \geq 0)$is the approximating polynomials of any kind. N is the degree of approximant, where in most cases the better approximate solution (i.e. close to the exact solution).

2.10 Boubaker Polynomials: *given as*

The Boubaker Polynomials method has been initially defined with the physical study in order to get an analytical solution for the heat equation. The Boubaker polynomials have been defined as follows:

$$B_j(p) = \sum_{i=0}^{(j/2)} (-1)^{-i} \binom{j-1}{i} \frac{j-4i}{j-i} p^{j-2i}, j \geq 1 \quad (9)$$

The first sixth Boubaker polynomials are given as

$$\left.\begin{aligned} B_0(p) &= 1 \\ B_1(p) &= p \\ B_2(p) &= p^2 + 2 \\ B_3(p) &= p^3 + p \\ B_4(p) &= p^4 - 2 \\ B_5(p) &= p^5 - p^3 - 3p \\ B_6(p) &= p^6 - 2p^4 - 3p^2 + 2 \end{aligned}\right\} \quad (10)$$

The three-term recurrence relation is given by

$$B_j(p) = pB_{j-1}(p) - B_{j-2}(p), j > 2 \quad (11)$$

3. METHODOLOGY

3.1 Introduction

In this section, we will introduce the transformation of higher order linear ordinary differential equations into integral equations by assuming an approximate solution of degree $N = 3$ using Boubaker polynomials method with the help of two collocation points.

3.2 PROBLEM CONSIDERED.

The higher-order linear initial value problem considered is of the form:

$$a_n\delta^{(n)}(p) + a_{n-1}\delta^{(n-1)}(p) + a_{n-2}\delta^{(n-2)}(p) + \cdots + a_2\delta''(p) + a_1\delta'(p) + a_0\delta(p) = \varphi(p) \quad (12)$$

Subject to the initial conditions:

$$\delta(p_0) = \delta_0, \quad \delta'(p_0) = \delta_1, \quad \delta''(p_0) = \delta_2, \ldots, \delta^{(n-1)}(p_0) = \delta_{n-1} \quad (13)$$

where $a's$ are constants; $\varphi(x)$ is the unknown function to be determined.

3.2.1 Standard collocation point using Boubaker Polynomials

In order to solve equation (12) and subject to initial conditions (13) using the standard collocation method we assumed an approximate solution of the form:

$$\delta(p) = \sum_{i=0}^{N} \rho_i B_i^*(p), \quad (14)$$

where $\rho_i, i = 1,2, \ldots, N$ are unknown constants to be determined, N is the degree of approximation, $B_i^*(p)(i \geq 0)$ is the approximating polynomial (Boubaker polynomials) of any kind defined in chapter one above.

Differentiating equation (14) n-times, we obtain

$$\left.\begin{aligned} \delta'(p) &= \sum_{i=0}^{N} \rho_i B_i^{*\prime}(p), \\ \delta''(p) &= \sum_{i=0}^{N} \rho_i B_i^{*\prime\prime}(p), \\ \delta'''(p) &= \sum_{i=0}^{N} \rho_i B_i^{*\prime\prime\prime}(p), \\ &\vdots \\ \delta^n(p) &= \sum_{i=0}^{N} \rho_i B_i^{*n}(p) \end{aligned}\right\} \quad (15)$$

Substituting equations (14) and (14) into equation (12), we obtain

$a_n \sum_{i=0}^{N} \rho_i B_i^*(p)^{(n)} + a_{n-1} \sum_{i=0}^{N} \rho_i B_i^*(p)^{(n-1)} + a_{n-2} \sum_{i=0}^{N} \rho_i B_i^*(p)^{(n-2)} + \cdots +$
$a_2 \sum_{i=0}^{N} \rho_i B_i^{*''}(p) + a_1 \sum_{i=0}^{N} \rho_i B_i^{*'}(p) + a_0 \sum_{i=0}^{N} \rho_i B_i^*(p) = \varphi(p),\ a_n \neq$
0 (16)

Integrating L.H.S and R.H.S of equation (16) with respect to **t,** we obtain

$a_n \int_{p_0}^{p} \left(\sum_{i=0}^{N} \rho_i B_i^*(t)^{(n)}\right) dt + a_{n-1} \int_{p_0}^{p} \left(\sum_{i=0}^{N} \rho_i B_i^*(t)^{(n-1)}\right) dt +$
$a_{n-2} \int_{p_0}^{p} \left(\sum_{i=0}^{N} \rho_i B_i^*(t)^{(n-2)}\right) dt + \cdots + a_2 \int_{p_0}^{p} \left(\sum_{i=0}^{N} \rho_i B_i^{*''}(t)\right) dt +$
$a_1 \int_{p_0}^{p} \left(\sum_{i=0}^{N} \rho_i B_i^{*'}(t)\right) dt + a_0 \int_{p_0}^{p} \left(\sum_{i=0}^{N} \rho_i B_i^*(t)\right) dt = \int_{p_0}^{p} \varphi(t) dt$ (17)

$a_n \left[\sum_{i=0}^{N} \rho_i B_i^*(p)^{(n-1)} - \sum_{i=0}^{N} \rho_i B_i^*(p_0)^{(n-1)}\right] + a_{n-1} \left[\sum_{i=0}^{N} \rho_i B_i^*(p)^{(n-2)} -$
$\sum_{i=0}^{N} \rho_i B_i^*(p_0)^{(n-2)}\right] + \cdots + a_2 \left[\sum_{i=0}^{N} \rho_i B_i^{*'}(p) - \sum_{i=0}^{N} \rho_i B_i^{*'}(p_0)\right] + a_1 [\sum_{i=0}^{N} \rho_i B_i^*(p) -$
$\sum_{i=0}^{N} \rho_i B_i^*(p_0)] + a_0 \int_{p_0}^{p} \left(\sum_{i=0}^{N} \rho_i B_i^*(t)\right) dt = \int_{p_0}^{p} \varphi(t) dt$
(18)

Putting the initial conditions provided in equation (13) into (18), we get

$a_n \left[\sum_{i=0}^{N} \rho_i B_i^*(p)^{(n-1)} - \delta_{n-1}\right] + a_{n-1} \left[\sum_{i=0}^{N} \rho_i B_i^*(p)^{(n-2)} - \delta_{n-2}\right] + \cdots + a_2 \left[\sum_{i=0}^{N} \rho_i B_i^{*'}(p) -$
$\delta_1\right] + a_1 [\sum_{i=0}^{N} \rho_i B_i^*(p) - \delta_0] + a_0 \int_{p_0}^{p} \left(\sum_{i=0}^{N} \rho_i B_i^*(t)\right) dt =$
$\int_{p_0}^{p} \varphi(t) dt$ (19)

Expanding equation (19), we obtain

$a_n \sum_{i=0}^{N} \rho_i B_i^*(p)^{(n-1)} - a_n \delta_{n-1} + a_{n-1} \sum_{i=0}^{N} \rho_i B_i^*(p)^{(n-2)} - a_{n-1} \delta_{n-2} + \cdots +$
$a_2 \sum_{i=0}^{N} \rho_i B_i^{*'}(p) - a_2 \delta_1 + a_1 \sum_{i=0}^{N} \rho_i B_i^*(p) - a_1 \delta_0 + a_0 \int_{p_0}^{p} \left(\sum_{i=0}^{N} \rho_i B_i^*(t)\right) dt = \int_{p_0}^{p} \varphi(t) dt$
(20)

Integrating both sides of side equation (20) with respect to u, we obtain

$a_n \int_{p_0}^{p} \left(\sum_{i=0}^{N} \rho_i B_i^*(u)^{(n-1)}\right) du - a_n \delta_{n-1} \int_{p_0}^{p} du +$
$a_{n-1} \int_{p_0}^{p} \left(\sum_{i=0}^{N} \rho_i B_i^*(u)^{(n-2)}\right) du - a_{n-1} \delta_{n-2} \int_{p_0}^{p} du + \cdots + a_2 \int_{p_0}^{p} \left(\sum_{i=0}^{N} \rho_i B_i^{*'}(u)\right) du -$
$a_2 \delta_1 \int_{p_0}^{p} du + a_1 \int_{p}^{p} \left(\sum_{i=0}^{N} \rho_i B_i^*(u)\right) du - a_1 \delta_0 \int_{p_0}^{p} du + a_0 \int_{p_0}^{p} \int_{u_0}^{u} \left(\sum_{i=0}^{N} \rho_i B_i^*(t)\right) dt du =$
$\int_{p_0}^{p} \int_{u_0}^{u} \varphi(t)\, dt du$ (21)

$a_n \int_{p_0}^{p} \left(\sum_{i=0}^{N} \rho_i B_i^*(u)^{(n-1)}\right) du - a_n \delta_{n-1} p + a_{n-1} \int_{p_0}^{p} \left(\sum_{i=0}^{N} \rho_i B_i^*(u)^{(n-2)}\right) du - a_{n-1} \delta_{n-2} p +$
$\cdots + a_2 \int_{p_0}^{p} \left(\sum_{i=0}^{N} \rho_i B_i^{*'}(u)\right) du - a_2 \delta_1 p + a_1 \int_{p_0}^{p} \left(\sum_{i=0}^{N} \rho_i B_i^*(u)\right) du - a_1 \delta_0 p +$
$a_0 \int_{p_0}^{p} \int_{u_0}^{u} \left(\sum_{i=0}^{N} \rho_i B_i^*(t)\right) dt du = \int_{p_0}^{p} \int_{u_0}^{u} \varphi(t)\, dt du$ (22)

$a_n \left[\sum_{i=0}^{N} \rho_i B_i^*(p)^{(n-2)} - \sum_{i=0}^{N} \rho_i B_i^*(p_0)^{(n-2)}\right] + \cdots + a_2 [\sum_{i=0}^{N} \rho_i B_i^*(p) - \sum_{i=0}^{N} \rho_i B_i^*(p_0)] -$
$a_2 \delta_1 p + a_1 \int_{p_0}^{p} \left(\sum_{i=0}^{N} \rho_i B_i^*(u)\right) du - a_1 \delta_0 p + a_0 \int_{p_0}^{p} \int_{u_0}^{u} \left(\sum_{i=0}^{N} \rho_i B_i^*(t)\right) dt du =$
$\int_{p_0}^{p} \int_{u_0}^{u} \varphi(t)\, dt du$ (23)

$a_n \left[\sum_{i=0}^{N} \rho_i B_i^*(p)^{(n-2)} - \delta_{n-2}\right] + \cdots + a_2 [\sum_{i=0}^{N} \rho_i B_i^*(p) - \delta_0] - a_2 \delta_1 p +$
$a_1 \int_{p_0}^{p} \left(\sum_{i=0}^{N} \rho_i B_i^*(u)\right) du - a_1 \delta_0 p + a_0 \int_{p_0}^{p} \int_{u_0}^{u} \left(\sum_{i=0}^{N} \rho_i B_i^*(t)\right) dt du = \int_{p_0}^{p} \int_{u_0}^{u} \varphi(t)\, dt du$ (24)

Expanding equation (24) and substituting the initial conditions provided in equation (13), we obtain

$a_n \sum_{i=0}^{N} \rho_i B_i^*(p)^{(n-2)} - a_n \delta_{n-2} + \cdots + a_2 \sum_{i=0}^{N} \rho_i B_i^*(p) - a_2 \delta_0 - a_2 \delta_1 p +$
$a_1 \int_{p_0}^{p} \left(\sum_{i=0}^{N} \rho_i B_i^*(u)\right) du - a_1 \delta_0 p + a_0 \int_{p_0}^{p} \int_{u_0}^{u} \left(\sum_{i=0}^{N} \rho_i B_i^*(t)\right) dt du =$
$\int_{p_0}^{p} \int_{u_0}^{u} \varphi(t)\, dt du$ (25)

Hence, equation (3.14) is collocated at the point $p = p_j$ to obtain

$a_n \sum_{i=0}^{N} \rho_i B_i^*(p_j)^{(n-2)} - a_n\delta_{n-2} + \cdots + a_2 \sum_{i=0}^{N} \rho_i B_i^*(p_j) - a_2\delta_0 - a_2\delta_1 p_j + a_1 \int_{p_0}^{p_j} (\sum_{i=0}^{N} \rho_i B_i^*(u))\, du - a_1\delta_0 p_j + a_0 \int_{p_0}^{p_j}\int_{u_0}^{u} (\sum_{i=0}^{N} \rho_i B_i^*(t))\, dtdu = \int_{p_0}^{p_j}\int_{u_0}^{u} \varphi(t)\, dtdu$ (26)

Thus $p_j = a + \frac{(b-a)}{N+1} j,\ j = 0,1,2,\dots,N$ (27)

Thus, equation (16) is then put into matrix form as

$$\boldsymbol{AX} = \boldsymbol{D} \quad (28)$$

$$\boldsymbol{A} = \begin{pmatrix} A_{11} & A_{12} & A_{13} & A_{14} \dots & A_{1,N+1} \\ A_{21} & A_{22} & A_{23} & A_{24} \dots & A_{2,N+1} \\ A_{31} & A_{32} & A_{33} & A_{34} \dots & A_{3,N+1} \\ & & \vdots & & \\ A_{N+1,1} & A_{N+1,2} & A_{N+1,3} & A_{N+1,4} \dots & A_{N+1,N} \end{pmatrix} \quad (29)$$

$$\boldsymbol{P} = (\rho_0,\ \rho_1, \rho_2, \rho_3 \dots, \rho_N)^T \quad \boldsymbol{D} = \big(f(\tau_1), f(\tau_2), f(\tau_3), \dots, f(\tau_N)\big)^T$$

where $A_N^{\prime s}$ are the coefficients of $\rho_N^{\prime s}$ and the $f(\tau_N)$ are the given functions. The matrix inversion approach is then used to solve the system of equation in order to obtain the unknown constants.

$$\begin{pmatrix} \rho_0 \\ \rho_1 \\ . \\ . \\ . \\ . \\ . \\ \rho_N \end{pmatrix} = \begin{pmatrix} A_{11} & A_{12} & A_{13} & A_{14} \dots & A_{1,N+1} \\ A_{21} & A_{22} & A_{23} & A_{24} \dots & A_{2,N+1} \\ A_{31} & A_{32} & A_{33} & A_{34} \dots & A_{3,N+1} \\ & & \vdots & & \\ A_{N+1,1} & A_{N+1,2} & A_{N+1,3} & A_{N+1,4} \dots & A_{N+1,N} \end{pmatrix}^{-1} \begin{pmatrix} f(\tau_1) \\ f(\tau_2) \\ . \\ . \\ . \\ . \\ . \\ f(\tau_N) \end{pmatrix} \quad (30)$$

Thus, equation(26) produces $(N+1)$ algebraic linear equation in $(N+1)$ unknown function, $\rho_i (i = 0,1,2,\dots)$. Thus, the resulting algebraic linear equations are then solved using **Maple 18** software to obtain the unknown constants which are substituted back into the approximate solution given by equation (14).

3.2.2 Chebyshev Gauss-Lobatto collocation point using Boubaker Polynomials

In order to discuss this method, we assumed an approximate solution of the form

$\delta(\tau) = \sum_{i=0}^{N} \rho_i B_i^*(\tau),$ (31)

where $\rho_i,\ i = 0,1,2,\dots,N$ are unknown constants to be determined, and N are the degree of approximating polynomials and $B_i^*(p)(i \geq 0)$ is the Boubaker polynomials of any kind defined in section 3.2.1 above. And Chebyshev Gauss-Lobatto collocation point is given as

$$p_k = \cos\left(\frac{\pi k}{N}\right), \qquad k = 0,1,2,\dots,N \quad (32)$$

This method is similar to the above section (3.2.1), which gives rise to an algebraic linear equation in unknown constants. The resulting algebraic linear equations are then solved using **Maple 18** software to obtain the unknown constants, with collocation points that are also substituted back into the approximate solution given by equation (31)

4. NUMERICAL EXAMPLES AND RESULTS

In this section, we have demonstrated the transformation of higher order linear ordinary differential equations into integral equations by assuming an approximate solution of degree

$N = 3$ using Boubaker polynomials method with the help of two collocation points. The examples are solved to illustrate the accuracy and efficiency of the method using **Maple 18** software and comparisons were made between the two collocation methods.

4.1 Numerical Example 1

Consider the first order initial value problem of the ordinary differential equation of the form:

$$\delta' + 3\delta = 0, \quad (33)$$

With initial condition:

$$\delta(0) = 2. \quad (34)$$

The exact solution is given as:

$$\delta(p) = 2e^{-3p} \quad (35)$$

4.2 Numerical Example 2

Consider the first order initial value problem of the ordinary differential equation of the form:

$$\delta'' - 3\delta' + 2\delta = 0 \quad (36)$$

With initial condition:

$$\delta(0) = 4, \delta'(0) = 5 \quad (37)$$

The exact solution is given as:

$$\delta(p) = 3e^{p} + e^{2p} \quad (38)$$

4.3 Numerical Example 3

Consider the first order initial value problem of the ordinary differential equation of the form:

$$\delta''' + 4\delta' = p \quad (39)$$

With initial condition:

$$\delta(0) = 0, \delta'(0) = 0, \delta''(0) = 1 \quad (40)$$

The exact solution is given as:

$$\delta(p) = \frac{3}{16}(1 - cos2p) + \frac{1}{8}p^2 \quad (41)$$

4.4. PRESENTATION/TABLE OF RESULTS

Here, we present the results obtained by solving three numerical problems by the method discussed above using Boubakar polynomials as our basis functions and the following acronyms are adopted in the tables below

STCP: Standard collocation points;

CGLCP: Chebyshev Gauss-Lobatto collocation points

We define our Absolute as

$$Error = |\delta(Exact) - \delta(Approximate)|, \quad \sigma \leq \tau \leq \rho$$

Table 1: Results for numerical solution 1 (STCP for N=3)

x	$\delta(Exact\ solution)$	$\delta(Approximate\ solution)$	$Absolute\ error$
0.0	2.0000000	1.889192887	1.108071×10^{-1}
0.2	1.09762327218805	1.108979480616	1.135620×10^{-2}
0.4	0.602388423824404	0.615584131688	1.319570×10^{-2}
0.6	0.330597776443174	0.333362517352	2.764741×10^{-3}
0.8	0.181435906578825	0.186670314744	5.234408×10^{-3}
1.0	0.0995741367357278	0.099863201000	2.890642×10^{-4}

Table 2: Results for numerical solution 1 (CGLCP for N=3)

x	$\delta(Exact\ solution)$	$\delta(Approximate\ solution)$	$Absolute\ error$
0.0	2.00000000000000	2.000000004	4.0000×10^{-9}
0.2	1.09762327218805	2.38400000516	1.286376×10^{0}
0.4	0.602388423824404	2.19200000640	1.589611×10^{0}
0.6	0.330597776443174	0.43657143636	1.059736×10^{-1}
0.8	0.181435906578825	- 3.86971427632	4.051150×10^{0}
1.0	0.0995741367357278	- 11.71428570300	1.181385×10^{1}

Table 3: Results for numerical solution 2 (STCP for N=3)

x	$\delta(Exact\ solution)$	$\delta(Approximate\ solution)$	$Absolute\ error$
0.0	4.00000000000000	3.729699075	2.703009×10^{-1}
0.2	5.15603297212178	5.043439549216	1.125934×10^{-1}
0.4	6.70101502141628	6.564063375096	1.369516×10^{-1}
0.6	8.78647332390808	8.556707900688	2.297654×10^{-1}
0.8	11.6296552098725	11.286510474040	3.43144×10^{-1}
1.0	15.5439015843078	15.018608443200	5.25293×10^{-1}

Table 4: Results for numerical solution 2 (CGLCP for N=3)

x	$\delta(Exact\ solution)$	$\delta(Approximate\ solution)$	$Absolute\ error$
0.0	4.00000000000000	4.000000000000	0.000000000
0.2	5.15603297212178	5.261490888920	1.054579×10^{-1}
0.4	6.70101502141628	6.952887907040	2.518728×10^{-1}
0.6	8.78647332390808	9.156885698200	3.704123×10^{-1}
0.8	11.6296552098725	11.956178906240	3.265237×10^{-1}
1.0	15.5439015843078	15.433462175000	1.104394×10^{-1}

Table 5: Results for numerical solution 3 (STCP for N=3)

x	$\delta(Exact\ solution)$	$\delta(Approximate\ solution)$	$Absolute\ error$
0.0	0.000000000000000	0.006249748	6.249748×10^{-3}
0.2	0.019801063624459	0.0199045928120	1.0352919×10^{-4}
0.4	0.076867491997407	0.0760798675600	7.8762444×10^{-4}
0.6	0.164557921035624	0.1637615228920	7.963981×10^{-4}
0.8	0.272974910431492	0.2719355094560	1.0394009×10^{-3}
1.0	0.390527531852589	0.3895877779000	9.397540×10^{-4}

Table 6: Results for numerical solution 3 (CGLCP for N=3)

x	$\delta(Exact\ solution)$	$\delta(Approximate\ solution)$	$Absolute\ error$
0.0	0.000000000000000	$-1.\ 10^{-10}$	$1.\ 10^{-10}$
0.2	0.019801063624459	0.0100696863096	9.731377×10^{-3}
0.4	0.076867491997407	0.0608710800328	1.59964119×10^{-2}
0.6	0.164557921035624	0.1574216026712	7.136318×10^{-3}
0.8	0.272974910431492	0.3047386758264	3.1763765×10^{-2}
1.0	0.390527531852589	0.5078397211000	1.173121×10^{-1}

4.5 GRAPHICAL REPRESENTATION

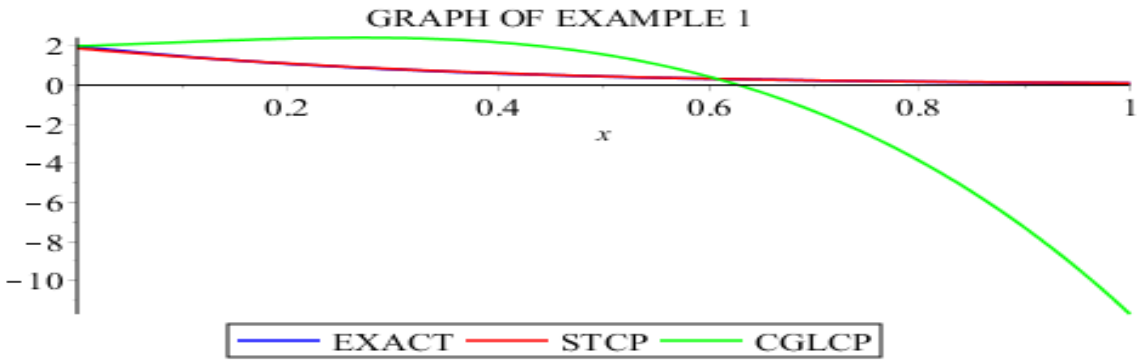

Figure 1: shows the exact, standard collocation points and Chebyshev Gauss-Lobbato Collocation Points.

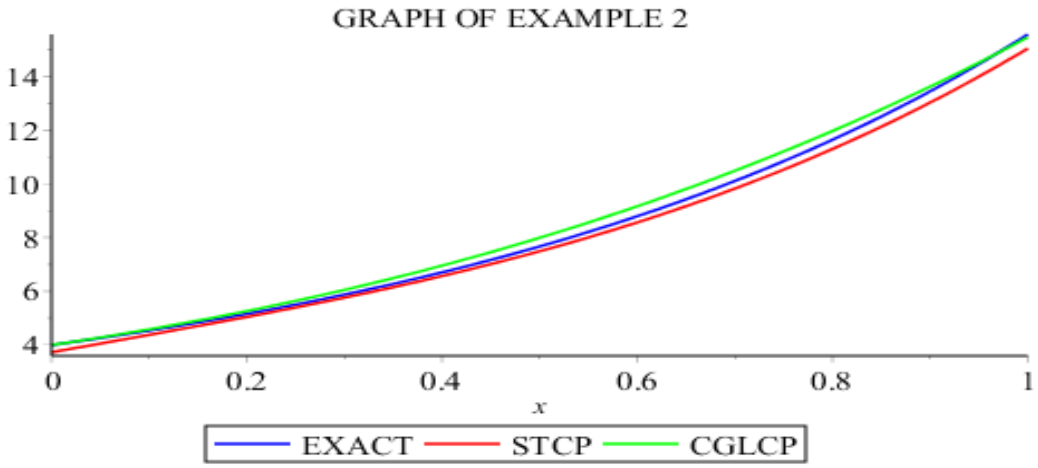

Figure 2: shows the exact, standard collocation points and Chebyshev Gauss-Lobbato Collocation Points.

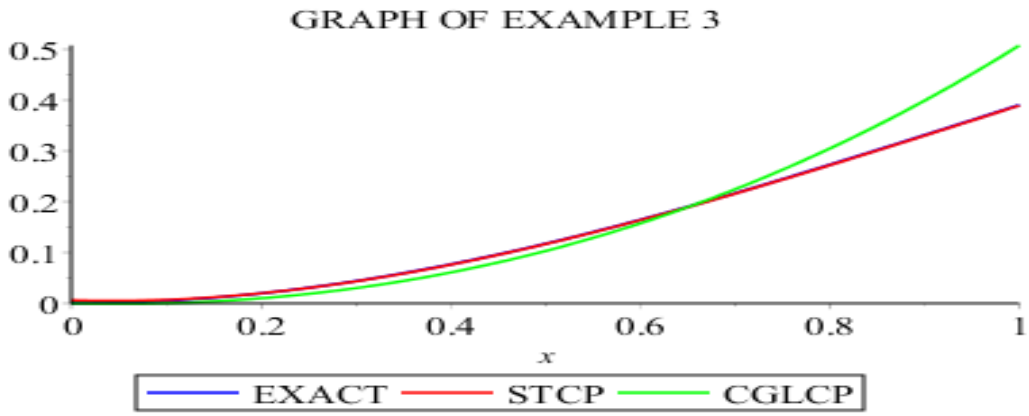

Figure 3: shows the exact, standard collocation points and Chebyshev Gauss-Lobbato Collocation Points.

5. CONCLUSION

This research presents a reliable, accurate, and efficient numerical approach for solving linear higher-order initial value problems of ordinary differential equations. The study employed and compared the Standard Collocation and Chebyshev–Gauss–Lobatto Collocation methods, both utilizing Boubaker polynomials as basis functions. Results obtained from three illustrative examples, each involving a single trial solution, indicate that the Standard Collocation method consistently outperforms the Chebyshev–Gauss–Lobatto point. As the approximation degree (M) increases, the computed solutions exhibit improved accuracy, converging towards the exact solution. While all solution plots initially align closely, the numerical error tends to increase with larger values of M, diverging slightly from the exact solution. All computations and graphical analyses were performed using MAPLE 18 software.

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